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DEVELOPMENT OF ACQUISITION STRATEGIES FOR THE COMMON MULTI-MODE--ETC(U)
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FINAL REPORT

DEVELOPMENT OF ACQUISITION STRATEGIES FOR THE COMMON MULTI-MODE RADAR PROGRAM

January 1980

Prepared for
DEPUTY FOR AERONAUTICAL EQUIPMENT (ASD/AE)
AERONAUTICAL SYSTEMS DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, DAYTON, OHIO 45433
under Contract F0-603-78-G-4125

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FOREWORD

This report was prepared by ARINC Research Corporation for the Aeronautical Systems Division's Deputy for Aeronautical Equipment (ASD/AE) under Contract FO-603-78-G-4125. It presents the results of a four-month examination into several acquisition strategies for procuring Common Multi-Mode Radars (CMMRs) for five candidate U.S. Air Force aircraft. The main objective of the study was to perform specialized trade-off analyses to assist the ASD Program Manager in formulating the system definition phase of the CMMR program.

ARINC Research wishes to acknowledge the excellent cooperation received from the Air Force representatives who participated in the investigation. We appreciate particularly the guidance and support provided by the program manager, Major Carl Canter; the ASD/EN CMMR technical coordinator, Mr. Ronald Longbrake; and the AFLC liaison officer assigned to ASD/AE, Captain Rod Fisher.

FOREWORD

This report was prepared by ARINC Research Corporation for the Aeronautical Systems Division's Deputy for Aeronautical Equipment (ASD/AE) under Contract FO-603-78-G-4125. It presents the results of a four-month examination into several acquisition strategies for procuring Common Multi-Mode Radars (CMMRs) for five candidate U.S. Air Force aircraft. The main objective of the study was to perform specialized trade-off analyses to assist the ASD Program Manager in formulating the system definition phase of the CMMR program.

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ABSTRACT

This report presents the results of a four-month examination into several acquisition strategies for procuring a Common Multi-Mode Radar (CMMR) for five candidate U.S. Air Force aircraft with the objective of assisting in the development of the program system definition phase. The study analyzes the payback and cost benefits to be derived from the program, considering the effect of factors such as reliability, schedule, and quantities. The report highlights the major issues surrounding the initiation of a common radar program and focuses on the key decisions required before the CMMR development and test phase can begin. The report also discusses radar design and standardization considerations and the present Air Force radar technology and modification programs as they relate to the acquisition strategies.

EXECUTIVE SUMMARY

1. SCOPE

This report presents the results of a four-month examination into several acquisition strategies for procuring a Common Multi-Mode Radar (CMMR) for five candidate U.S. Air Force aircraft with the objective of assisting in the development of the program system definition phase. The study reviews the potential market size and other factors such as reliability, schedule, and quantities. The report highlights the major issues surrounding the initiation of a common radar program and focuses on the key decisions required before the CMMR development and test phase can begin. The report also reviews existing candidate aircraft radar capabilities and modification programs and present Air Force radar technology efforts, describes the various operating modes that are desired or available in a modern radar system, and discusses clutter, target detection, and other design considerations.

2. BACKGROUND

The need for a detailed review of attack aircraft radar programs was highlighted at the First and Second Air Force Avionics Planning Conferences held during 1978, where the development of a Common Multi-Mode Radar was proposed as a candidate for standardization. The conferees recommended that a commonality and life-cycle-cost (LCC) study be performed as soon as possible to determine the feasibility of a common radar approach to solve existing supportability problems and meet future operational requirements. This review, completed late in 1978 and known as the "ASD Common Radar Study," concluded that the use of a common radar for multiple aircraft applications was technically feasible and that this approach might provide sizable development, procurement, and support cost benefits. As a result of the study and recommendations from the planning conferences, the Air Force established a new program element (P.E. 64412) with an anticipated program start in fiscal 1981.

Subsequently, in the Avionics Master Plan (AMP), dated July 1979, the Deputy for Avionics Control recommended that the program be moved forward a year to take maximum advantage of the potential market -- especially the possibility of simultaneously developing a CMMR to meet technical and schedule requirements of an advanced radar being proposed for the F-16 and

replacement radars for other aircraft. After the publication of the AMP, the Air Staff directed AFSC to develop a joint command briefing that would address the issues surrounding the CMMR program with the objective of establishing a program management plan by late October 1979. During the recent 1979 Armament and Avionics Planning Conference the CMMR program was again reviewed and supported. An overall acquisition strategy, however, has not been determined.

3. TASK DESCRIPTION

Our tasks, as defined in the statement of work, were to assist in the development and evaluation of acquisition strategies for a CMMR. Three tasks were defined.

Task 1: Perform Trade-Off and Risk Analyses

Under this task, trade-off and risk analyses of tasks identified or approved by the ASD program office were performed. Management considerations subjected to qualitative and quantitative risk and schedule analyses included the following:

- Sequential versus parallel CMMR developments
- LRU modular standardization versus system standardization
- Cost payback as a function of aircraft applications
- Competitive acquisition payoffs or penalties as a function of learning-curve rates

Task 2: Develop CMMR Program Matrixes

On the basis of the results of the trade-off analyses of Task 1, program matrixes were developed to highlight the pertinent program factors under numerous specific sets of assumptions to assist the Air Force in defining an optimum CMMR program.

Task 3: Define Acquisition Alternatives

On completion of Task 2, we prepared formats of several system program definition approaches with justification rationale from the program matrixes.

Our definition of an acquisition strategy used in this report is that it includes different investment methods from development through procurement, including the initial support concept.

4. TECHNICAL APPROACH

As a first step, ARINC Research reviewed nine present and planned radar technology efforts and the work performed under the ASD Common Radar

Study. We analyzed the potential market for cost payback potential and performed qualitative risk and schedule analyses using the data developed during the ASD Study to support the program described in the AMP.

On the basis of these trade-off analyses we developed two planning checklists, a decision table, and a program matrix that highlight the pertinent program factors. A number of alternatives were reviewed with the program manager during development and presentation of the joint command briefings. Only the most significant are discussed in this report. Additional information concerning alternative support strategies is also provided.

Our technical approach is shown graphically in Figure S-1.

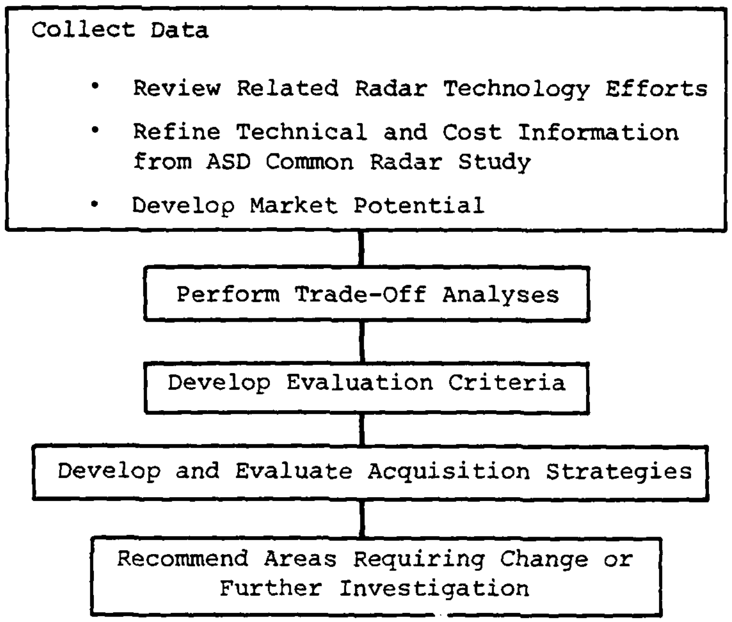

Figure S-1. STUDY APPROACH

5. TECHNOLOGY SYNCHRONIZATION

There are a number of continuing radar technology programs that should be synchronized to provide the most cost-effective and timely implementation of the CMMR program. Table S-1 highlights their anticipated technology outputs and suggests several changes. The CMMR program will require technology from these efforts; however, in many cases the scheduling of the development projects feeding CMMR will not meet the F-16 effectivity date. As is shown in the report, the majority of the near-term data required by the CMMR program in 1980 are in the form of software algorithms. Under the present schedules, it is possible to transfer most of these algorithms (in unvalidated form) to the CMMR program for checkout and test during the F-16 flight test program proposed for fiscal 1981. Additional research and

development funding would be required to ensure timely technology transfer to the CMMR dual source program proposed by the ASD.

6. TRADE-OFF AND RISK ANALYSES

We examined the potential market for a CMMR on the basis of the ASD Common Radar Study and responses from the using commands [Tactical Air Command (TAC), Strategic Air Command (SAC), and Air Defense Command (ADCOM)]. The potential market consists of five candidate aircraft: F-16, F-106, F-4, F/FB-111, and B-52. The size of the market is quite sensitive to the timing of CMMR acquisition. F-16 aircraft production after fiscal 1984 is projected at 10 per month; a delay in CMMR production reduces the total market by the number of aircraft already produced. We assumed that CMMRs would be available starting in March 1984, resulting in a potential F-16 market for 678 radars, and a total market of over 2400 radars (not including spares). The second factor driving the market timing is the poor reliability of the F-106 radar, which makes early replacement extremely important. Extensive delay in CMMR may cause the loss of other aircraft from the market besides a reduction of over 200 radars for the F-106.

Table S-1. TECHNOLOGY PROGRAMS REVIEWED

Title	Program Element/Project	Remarks
Radar Programmable Signal Processor (RPSP)	64201/2519	Transfer software to F-16 as soon as possible
Non-Cooperative Target Recognition (NCTR)	63742/1177	Accelerate program and transfer software to F-15 as soon as possible
ECCM Radar Improvement Program (ERIP)	64201/2259	Transfer applicable portions to CMMR
Advanced Strike Radar Technology (ASRAT)	63203/69DF	Combine program with CMMR
Advanced Fighter Technology Integration (AFTI)	63205/2506 63245/2061	Closely coordinate efforts with ASRAT; develop CMMR to be compatible
Low Altitude Navigation Targeting Infrared For Night (LANTIRN)	63249/2693	Interim manual terrain-following system for F-16 and A-10
Assault Breaker (PAVE MOVER)	63747/2217	Closely coordinate efforts with ASRAT
Advanced Medium Range Air-To-Air Missile (AMRAAM)	63370/2437	Develop CMMR to be compatible
Electronically Agile Radar (EAR)	63241/1206	Programmable Signal Processor (PSP) software is potential technology source for CMMR

Payback dates for each of the candidate aircraft were calculated from data developed by ASD. Table S-2 summarizes the payback dates under various conditions of inflation or logistic support cost (LSC) growth. The F-16 payback was not calculated because CMMR will be installed in production aircraft.

Table S-2. PAYBACK DATE FOR REPLACEMENT RADARS

Aircraft	Rate of Logistics Cost Increase		
	8 Percent	10 Percent	15 Percent
F-106	2002	1998	1994
F-111	2001	1998	1994
FB-111	2000	1997	1993
F-4E	2009	2002	1996
B-52G	2004	1999	1994
B-52H	2001	1997	1993

The sensitivity of these payback dates to factors such as installation rates, installation start dates, existing radar and CMMR logistic support costs, and unit costs was examined for the "worst case" (latest payback) candidate, the F-4E. We found them most sensitive to installation rate, the MTBF achieved by the CMMR and present LSCs. A reasonable F-4E scenario, consisting of a mildly accelerated installation rate (40 per quarter instead of 30), a decrease in existing radar MTBF (4 hours instead of 6.8 hours), and growth in present logistics support costs of 15 percent produced a new F-4E payback date of 1993 from the "baseline" of 2009.

We also examined the potential acquisition savings of common development and procurement and split-buying over separate development and procurement and found the potential savings to be in excess of 900 million then-year dollars for a common program and 630 million dollars for the split-buy program, wherein two parallel developments are pursued.

Finally, we examined the issues of full versus minimum standardization. The CMMR program, because of its immature technology and architectural interdependence, does not make a good candidate for system-level standardization. However, we believe that an alternative -- LRU/SRU standardization -- has merit and should cost only slightly more than full standardization (approximately 15 percent).

7. ACQUISITION STRATEGIES

We examined three acquisition strategies - sole source, full competition, and dual source. Each of these strategies is shown to display certain advantages as well as disadvantages. However, given the particular circumstances of schedule and budget, the dual source strategy, wherein two candidate radars are developed and a fly-off is used to select a winner, appears most favorable overall. The major disadvantage of this strategy is that it does not yield a "full up" CMMR at the outset but rather one with growth potential to achieve the advanced capability later on. Table S-3 rates the three strategies against requirements, economic factors, schedule considerations, and management control factors.

Several subsets to the dual source strategy, designed to increase competition, were addressed as well. These were the use of a leader-follower concept, teaming, and separate LRU buys with an integrating contractor. On the basis of our examination of these alternatives, we believe that teaming is the most practical of the three, but it is not without pitfalls. It requires that a prime contractor share some of his work. Provided that nearly identical hardware and software are required for all systems and the prime contractor is held responsible for ensuring that the requirements of all systems are met, teaming could foster greater competition. It appears that it is too late to attempt to use the leader-follower approach in CMMR because the two sources envisioned by ASD are already producing different high-technology systems that they would propose as the basis for CMMR.

8. CONCLUSIONS

As is shown in the analyses of Chapter Four, the CMMR benefits are potentially very large - as high as $900 million in acquisition cost savings alone if all the five candidate aircraft were to use a total of approximately 2,400 common radars. Paybacks for four of the five candidate aircraft could begin in the early 1990s. The analyses also concluded that these paybacks and the cost benefits are very sensitive to the existing radar logistic support costs and the anticipated reliability of the CMMR. Even if the market were reduced to approximately half, the cost benefits still appear to be sizable.

As pointed out in Chapter Six, before any specific CMMR acquisition strategy can be adopted, several key decisions are required. Final agreement must be reached on the CMMR operational requirements (operating modes). Technical requirements such as nuclear hardening also must be established. With the exception of the F-4E and F-106, all the candidate aircraft have the alternative of modifying existing hardware. While that alternative is not attractive from a cost standpoint, it would help the Air Force meet schedule demands. After CMMR requirements have been firmly established, the market size must be calculated more precisely because this will have a substantial effect on the acquisition strategy selected.

Table S-3. RANKING OF CMMR ACQUISITION STRATEGIES

Ranking Criteria	Strategy: Sole Source	Dual Source	Full Competition	Comments
REQUIREMENTS				
Operational				
CMMR	○	□	●	
F-106	●	□	○	Can Be Met Now
Technical				
Technology Transfer	○	□	●	
Growth Provision	○	□	●	
Aircraft Interfaces	○	□	●	Assumes More Than One Aircraft
ECONOMIC				
Development Costs	●	□	○	Less Than $50M Available -- Go Sole-Source
Production Costs	○	□	●	
O&S Costs				
Reduce Existing	●	□	○	
Optimum CMMR	○	□	●	
Optimum LCC				
< 1,000 Radars	○	●	□	Sensitive to Market and Aircraft Types
> 1,000 Radars	○	□	●	
SCHEDULE				
< 4 years	●	--	--	Only Sole-Source Possible
4 to 6 years	□	●	○	
> 6 years	○	□	●	
MANAGEMENT CONTROL				
Overall PGM Flexibility	○	□	●	
Development and Production Costs	○	□	●	
Change Number of Aircraft Types	○	□	●	
Accommodate Threat Change	○	□	●	Unless Needed Now

Criteria Ranking: Most Attractive ●
Moderately Attractive □
Least Attractive ○

6. RECOMMENDATIONS

ARINC Research recommends that Air Force planners responsible for the CMMR effort take the following actions:

- Obtain a go/no-go decision on the F-106 Radar Upgrade and Modernization Modification (RUMM) program. AFLC has stated that the F-106 will be only "40 percent supportable" after fiscal 1985. The inclusion or exclusion of this aircraft is central to the acquisition strategy.
- Formally review all applicable 6.3 and 6.4 radar technology programs. Because these are generally not targeted for specific applications, the cognizant program offices have little awareness of their potential support to the CMMR program. Offices at the AX level or above should review these programs and provide guidance, especially in relation to scheduling, where needed inputs must be synchronized.
- Determine program costs more precisely. In particular, software development and support equipment costs need further refinement. These can be very large segments of CMMR life-cycle costs.
- Decide which hardware procurement strategy to follow. As indicated in the conclusions of this report, the acquisition strategy selected is very sensitive to the market size. At this time it appears that the leader-follower approach would be unnecessarily risky. Teaming might be a viable approach if the market approaches 1,000 radars and an additional manufacturer is required for competitive or schedule reasons.
- Develop a software acquisition strategy. It is evident that with the extent of embedded computers in its architecture, strategies should be developed for the acquisition of software as well as hardware for the CMMR program. This strategy should encompass the standards to be used (HOL, ATLAS, 1750, 1553, etc.) and the software support tools. A radar software focal point should also be established to monitor both the present technology programs and programs for the development of the CMMR signal processor and computer hardware.

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CHAPTER ONE

INTRODUCTION

1.1 SCOPE

This report presents the results of a four-month examination into several acquisition strategies for procuring a Common Multi-Mode Radar (CMMR) for five candidate U.S. Air Force aircraft with the objective of assisting in the development of the program system definition phase. The study analyzes the payback and cost benefits to be derived from the program, considering the effect of factors such as reliability, schedule, and quantities. The report highlights the major issues surrounding the initiation of a common radar program and focuses on the key decisions required before the CMMR development and test phase can begin. The report also considers radar design approaches, existing candidate aircraft radar capabilities, and the present Air Force radar technology and modification programs as they relate to the acquisition strategies. It was prepared by ARINC Research Corporation for the Aeronautical Systems Division's Deputy for Aeronautical Equipment (ASD/AE) under Contract F0-603-78-G-4125.

1.2 BACKGROUND

The need for a detailed review of attack aircraft radar programs was highlighted at the First and Second Air Force Avionics Planning Conferences, held during 1978, at which time the development of a Common Multi-Mode Radar was proposed as a candidate for standardization to reduce equipment proliferation and logistics support costs. The conferees recommended that a commonality and LCC study be performed as soon as possible to determine the feasibility of a common radar approach to solve existing supportability problems and meet future operational requirements. This review, completed late in 1978 and known as the "ASD Common Radar Study," concluded that the use of a common radar for multiple aircraft applications was technically feasible and that this approach might provide sizable development, procurement, and support cost benefits. As a result of the study and recommendations from the planning conferences, the Air Force established a new program element (PE 64412) with an anticipated program start in fiscal 1981.

Subsequently, in the Avionics Master Plan (AMP) dated July 1979, the Deputy for Avionics Control recommended that the program be moved forward

a year to take maximum advantage of the potential market -- especially the possibility of simultaneously developing a CMMR to meet technical and schedule requirements of an advanced radar being proposed for the F-16 and replacement radars for other aircraft. After the publication of the AMP, the Air Staff directed AFSC to develop a joint command briefing that would address the issues surrounding the CMMR program with the hope of establishing a program management plan by late October 1979. During the 1979 Armament and Avionics Planning Conference, the CMMR program was again reviewed and supported and the original road map was updated (Figure 1-1). (A road map is a device for showing alternative ways to move toward specific program objectives and associated goals.) Table 1-1 provides descriptions of nodal points on the road map.

At the time of publication of this study report, not all user requirements for CMMR were firm and the future of the program still had not been decided by the Air Force. This report provides insight into the key factors that must be considered by Air Force planners in that decision.

1.3 TASK DEFINITION

Our tasks, as specified in the statement of work, were to assist in the development and evaluation of acquisition strategies for a CMMR. Three tasks were defined:

Task 1: Perform Trade-Off and Risk Analyses

Under this task, we performed trade-off and risk analyses of factors identified or approved by the ASD program office. Management considerations subjected to qualitative and quantitative risk and schedule analyses included the following:

- Sequential versus parallel CMMR developments
- LRU modular standardization versus system standardization
- Cost payback as a function of aircraft applications
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On the basis of the results of the trade-off analyses of Task 1, we developed program matrixes that highlighted the pertinent program factors under numerous specific sets of assumptions to assist the Air Force in defining an optimum CMMR program.

Task 3: Define Acquisition Alternatives

Upon completion of Task 2, we prepared formats of several system program definition approaches with justification rationale from the program matrixes.

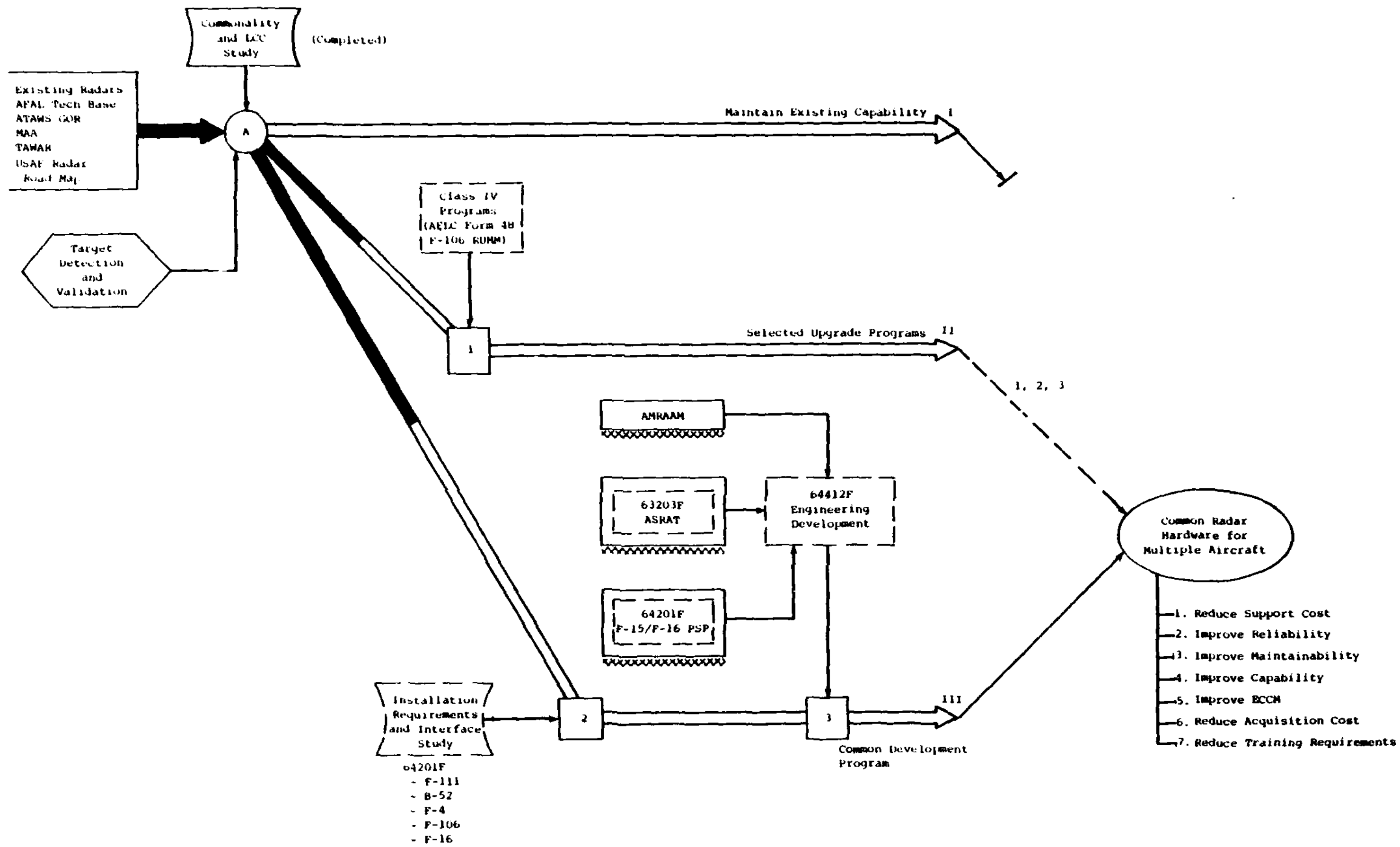

Figure 1-1. COMMON RADAR HARDWARE ROAD MAP

Table 1-1. COMMON RADAR HARDWARE ROAD MAP NODAL POINT DESCRIPTIONS

Path	Node	Title	Description	Status/ Suggested Action Agencies
	A		On the basis of the completed in-house study on common radar hardware and unique hardware and the scheduled briefing by ASD on the program plan and management plan, direction will be provided to implement required programs.	ASD/AE present briefing HQ USAF issue PMDs.
I		Maintain Existing Capability	The radars in existing aircraft will be maintained with associated support and performance capabilities.	
II	1	Selected Upgrade Programs	Individual radars will be upgraded to reduce support cost, improve reliability and maintainability. This approach could use some existing hardware or portions of the common radar hardware for upgrade. Presently AFLC has a Form 48 prepared for an F-106 radar upgrade using F-15 and F-18 radar components.	HQ AFLC initiate individual radar upgrades.
III	2	Common Radar Hardware Development RFP	The results of integration/interface studies contracted for by ASD with prime contractors will be used to prepare the development RFPs.	ASD/AE contract for studies and prepare RFPs.
III	3	Common Radar Hardware Engineering Development Program	Development aircraft integration/procurement of common and unique radar hardware for specific applications under program 64412F and other program elements in fiscal year 1980 and requiring, more than $100 million. In addition BP-1100, BP-1600, and BP-3010 funds will be required for production and retrofit. (Estimated radar recurring cost is $500,000 to $700,000 per copy, not including related aircraft changes).	ASD conduct development, aircraft integration and procurement.

Our definition of an acquisition strategy (as used in this report) is that it comprises all of the investment approaches from development through procurement, including the purchase of the initial support concept.

In addition to the above tasks, we also provided support to the ASD CMMR Program Manager in the development of program briefings required by the Air Staff.

1.4 TECHNICAL APPROACH

The technical approach used during the study is depicted in Figure 1-2. As a first step, we reviewed nine present and planned radar technology efforts and the work performed under the ASD Common Radar Study. We then analyzed the potential market and performed qualitative and quantitative risk and schedule analyses. These included the following:

- Cost payback date for each candidate aircraft
  - Effect due to change in present radar reliability
  - Effect due to change in CMMR logistics support costs
  - Effect due to change in CMMR unit cost
  - Effect due to change in installation rate
  - Effect due to change in CMMR installation schedule

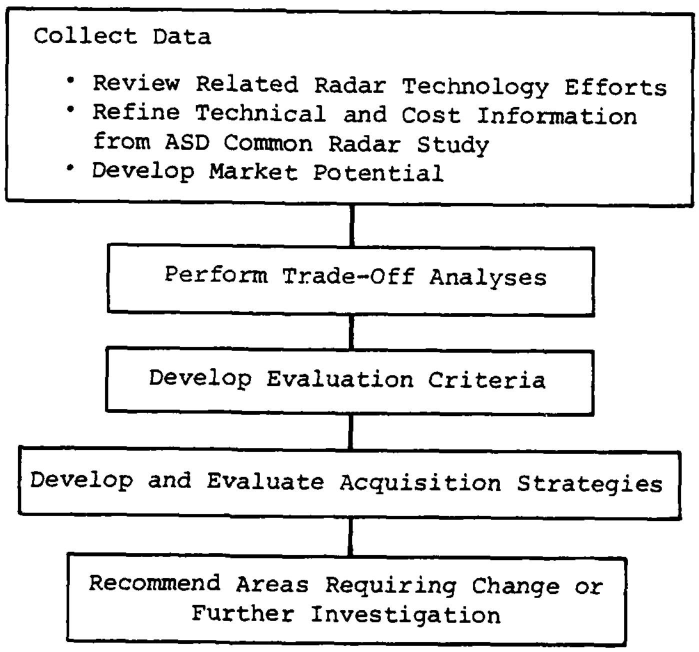

Figure 1-2. STUDY APPROACH

* Sequential versus parallel development and production
* Cost savings through common development and quantity buying

On the basis of these trade-off analyses, ARINC Research developed two planning checklists, a decision table, and a program matrix that highlight the pertinent program factors. Program alternatives were reviewed with the program manager during development and presentations of the joint command briefings. The most significant of these are discussed in this report. Additional information concerning alternative support strategies was also developed.

1.5 REPORT ORGANIZATION

Chapter Two summarizes the equipment characteristics for the radars installed in aircraft that have been identified as candidates for the CMMR program. In addition, it discusses programmed and proposed modifications to these radars.

Chapter Three examines selected Air Force attack radar technology programs to highlight possible duplications of efforts, to investigate the feasibility of combining programs, and to suggest alternatives that would permit timely transfer of technology to the CMMR program.

Chapter Four presents trade-off analyses that illuminate the sensitivities of the factors affecting the CMMR program.

Chapter Five examines several standardization approaches available to the CMMR program.

Chapter Six reviews the potential advantages and disadvantages of the major acquisition approaches available and briefly highlights some support considerations.

Chapter Seven provides a summary of our findings, draws conclusions, and presents some recommendations.

Appendix A describes the various operating modes that are desired or available in a modern radar system and discusses clutter, target detection, and other design considerations.

Appendix B discusses contractual warranty provisions and criteria and some advantages and disadvantages of various alternative methods for supporting the CMMR.

CHAPTER TWO

RADAR SYSTEM DEVELOPMENTS FOR CURRENT AIRCRAFT APPLICATIONS

2.1 INTRODUCTION

Over the past two decades aircraft radar systems have evolved from single-function designs to equipment capable of operating in many different modes. Attendant upon this increase in capability has been a reduction in both system size and weight, and the number of line replaceable units (LRUs). This evolution in radar system design has resulted in a wide variation of equipments presently installed in Air Force tactical aircraft, ranging from the limited mode, tube-type MA-1 in the F-106 to the multimode, all-digital-processing radar of the F-16. This spectrum of systems and lack of hardware commonality among existing radars add to maintenance and support costs because each system creates a need for different spares, support equipment, documentation, and training.

2.2 EXISTING RADAR CHARACTERISTICS

Table 2-1 presents a summary of the characteristics of the radars installed in aircraft that have been identified as candidates for the CMMR Program. The characteristics of the F-18 and F-15 radars are also shown for comparison. Table 2-1 was developed by assembling data gathered from radar contractors and Air Force Systems Command and Logistics Command personnel and by reviewing applicable technical orders and other radar documents. It illustrates that in the years between the production of the F-106 and the present, radar capabilities have increased in each new aircraft while the number of LRUs required has gone down. Advances in radar technology design have reduced the number of LRUs from a high of 55 in the F-106 to a low of 6 in the F-16. The recent advances in the most current production radars have continued to allow a reduction in LRUs from nine in the F-15 to only five in the F-18. This reduction in LRUs is expected to result in an increase in mean time between failures (MTBFs) because of the newer system architecture and smaller number of interfaces involved. For example, it is anticipated that the F-16 radar will have a field reliability of 90 hours by 1981. The F-18 radar system is expected to exceed this; it has a contract requirement for incremental growth to 106 hours MTBF. These projected MTBF figures for the F-16 and F-18 contrast sharply with the present F-106 MTBF of 2.2 hours and the F-4E MTBF of 6.8 hours.

Technology has also reduced the size and weight of the modern radar and the number of radar interfaces. A major advance contributing to the reduction of interfaces has been the avionics multiplex bus. With the advances in digital processing providing for a higher number of operating modes, the F-15, F-16, and F-18 will be able to do more with one radar set than the F-111D or B-52 can do with three different radar sets.

2.3 EXISTING RADAR MODES

There is no precise definition for the term "radar mode". There are major modes, submodes, selectable modes, and automatically occurring modes. A mode that is manually selectable in one aircraft may be automatic in another. In one aircraft the weapon selected determines the radar mode of operation; in another, the target detection range allows the radar to automatically select the weapon required: medium range missile, short range missile, or gun.

Table 2-2 lists the various modes and submodes that are desired in a modern airborne attack radar. A brief explanation of these radar modes is given in Appendix A.

The radar operational modes for the candidate CMMR aircraft as well as those of the F-18 and F-15 aircraft are shown in Tables 2-3 and 2-4. Table 2-3 shows the existing air-to-air (A/A) radar modes in each aircraft type, growth potential capability, and the desired modes. Table 2-4 identifies present air-to-ground (A/G) and special radar modes and the desired and growth potential modes. The desired and growth potential modes listed were taken from the ASD Common Radar Study and a Tactical Air Command list of required radar modes for the F-16, F-111, and F-106 aircraft. At the time of this study user requirements for the additional modes had not been established. The distinction between "growth potential" and "desired" is significant. Radar modes that could be incorporated into the framework of an existing system without major hardware changes are listed as growth potential rather than desired.

Figure 2-1 more clearly indicates the trend in today's requirements. As shown, the F-111D is the most advanced A/G fighter in the Air Force today, while the F-15 is the most advanced A/A one (from a radar viewpoint). There is no direct relationship between Figure 2-1 and Tables 2-3 and 2-4.

2.4 WEAPONS COMPATIBILITY

Table 2-5 illustrates current compatibility between aircraft radars and air-to-air armament. Both the AIM-4 Falcon and the AIM-7 Sparrow are semi-active radar homing missiles that require the use of a target illuminator. The AIM-4 is used only by the F-106. The F-16 has a growth potential in the radar for the AIM-7, and an AIM-7F has been successfully launched from a YF-16, but the aircraft does not presently have a target illuminator installed. A major limitation on the AIM-4 is its five-mile range; the advanced AIM-7F has a range in excess of 24 miles. The AIM-9

Table 2-1. CHARACTERISTICS OF EXISTING AIRCRAFT RADAR

Radar	APG-65	F-16 Radar	APG-63	APQ-113	APQ-110	APQ-144	APQ-146	APQ-130	APN-189	APQ-128	APQ-114	APN 185	APQ-134	APQ-120	MA-1	ASB-9A	ASB-16	ASG-15	ASG-21	APN-218
Aircraft	F-18	F-16	F-15	F-111A/E	F-111A/E	F-111F	F-111F	F-111D	F-111D	F-111D	FB-111	FB-111	FB-111	F-4E	F-106	B-52H	B-52G	B-52G	B-52H	B-52G/H
Radar Mission	Multimode	Multimode	Multimode	Attack	Terrain Following	Attack	Terrain Following	Attack	Doppler	Terrain Following	Attack	Doppler	Terrain Following	Fire Control	Fire Control	Bomb/Nav	Bomb/Nav	Tail Fire Control	Tail Fire Control	Doppler
Air-to-Air Modes	19	11	17	3	NA	3	NA	7	NA	NA	3	NA	NA	5	4	0	0	3	4	NA
Air-to-Ground Modes	14	7	3	1	1	3	2	8	1	4	3	1	2	2	0	3	3	0	0	1
Special Modes	2	1	4	1	0	1	0	2	0	0	2	0	0	2	0	3	3	0	0	0
LRUs, Less Racks, Wave Guides	5	6	9	8	10	8	12	8	2	9	8	3	11	23	55	47	47	32	12	2
Volume, Less Antenna (ft^3)	4.4	4.0	≈8.8	9.4	6.3 (IA)	9.4	6.1	10.5	1.7 (IA)	5.5	9.4	1.4	6.1	11.0	16.0	11.4	11.4	UD	19.3	2.5
Weight, Less Rack (lbs)	138	270	≈580	357	194	≈361	192	498	47	≈171	≈361	54	192	550	678	389	389	1,100	997	71
Rack Weight (lbs)	≈100	UD	UD	6	23	6	23	48	NA	≈23	6	3	23	117	83	418	418	500	UD	UD
Interfaces	6	5	21	9	11	8	14	6	5	13	8	1	12	16	UD	16	16	5	10	2
Input Power, AC	8.9 kVa	3.58 kVa	12.66 kVa	2.0 kVa	0.92 kVa	3.0 kVa	2.0 kVa	5.43 kVa	225 Va	2 kVa	3.0 kVa	125	2.0 kVa	6.6 kVa	10 kVa	13.5 kVa	13.5 kVa	18 kVa	20 kVa	276 Va
Input Power, DC	NA	230 W	750 W	120 W	120 W	120 W	150 W	46 W	2.5 W	150 W	120 W	UD	150 W	525 W	1.4 kW	550 W	550 W	2.4 kW	420 W	UD
Air Cooling (lb/min)	(3,000 W)	12	15.4	UD	UD	1.5	UD	29.7	0.4	UD	1.5	UD	UD	24	14.2	5.2	5.2	20	UD	UD
Liquid Cooling (GPM)	(4,850 W)	NA	1.8	NA	NA	NA	NA	4.7	NA	NA	NA	UD	NA	NA	NA	NA	NA	NA	NA	NA
MTBF	106 (CG)	9.9	15	4.0	UD	UD	UD	10.7	43	UD	3	50	UD	6.8	2.2	4.8	4.1	10.9	7.3	2,250
Manufacturer	Hughes	West.	Hughes	G.E.	T.I.	G.E.	T.I.	Rockwell	UD	T.I.	G.E.	Singer	T.I.	West.	Hughes	Raytheon	Raytheon	ARMA	Emerson	Teledyne

CG -- Contractor Guarantee.
IA -- Includes Antenna.
UD -- Undetermined.
NA -- Not Applicable.

Table 2-2. MAJOR RADAR OPERATIONAL MODES

Air-to-Air Modes	Air-to-Ground Modes
Air Combat • Rapid Search • Auto Acquisition •• Boresight •• Super Search •• Vertical Scan •• Auto Gun • Auto Track Normal Air • Look Up • Look Down • Manual Acquisition • Single Target Track • Track While Scan • Long Range Search • Velocity Search • Range While Search • Short Range Search • Identification (IFF) • Non-Cooperative Target Recognition • Raid Assessment Target Illumination Helicopter Detection	Ground Mapping • Spoiled Beam • Real Beam • High Resolution •• Doppler Beam Sharpening •• Synthetic Aperture Radar • Freeze • Expand Air To Ground Ranging Ground Moving Target • Fast Moving Target • Slow Moving Target Fixed Target Track Ship Detection and Track Navigation Update • Position • Velocity Terrain Avoidance Terrain Following **Special Modes** Beacon ECCM TV SNIFF

Table 2-3. EXISTING AND DESIRED AIR-TO-AIR RADAR MODES

Air-to-Air Modes	Aircraft Types										
	F-18	F-16	F-15	F-111A	F-111D	F-111E	F-111F	FB-111	F-4E	F-106	B-52
Air Combat	X	X	X						D	D	D
• Rapid Search	X	X	X						D	D	D
• Auto Acquisition	X	X	X						D	D	D
•• Boresight	X		X		X						
•• Super Search	X	X	X								
•• Vertical Scan	X	X	X								
•• Auto Gun	X	X	X								
• Auto Track	X	X	X						D	D	D
Normal Air	X	X	X	X	X	X	X	X	X	X	X
• Look Up	X	X	X	X	X	X	X	X	X	X	X
• Look Down	X	X	X	D	X	D	D	D	D	D	
• Manual Acquisition	X	X	X	X	X	X	X	X	X	X	X
• Single-Target Track	X	X	X	X	X	X	X	X	X	X	
• Track While Scan	X	GP	GP						D	D	X
• Long-Range Search	X	GP	X								
• Range While Search	X	D	X								
• Velocity Search	X	D	X								
• Short-Range Search	X	D	X								
• Identification (IFF)	X	X	X		X				X	D	
• Noncooperative Target Recognition	GP	D	D						D	D	
• Raid Assessment	X	D	GP						D	D	
Target Illumination	X	GP	X		X				X	X	
Helicopter Detection		GP	GP						D		

X = Existing.
GP = Growth potential (possible with present hardware).
D = Desired (requires new hardware).

Table 2-4. EXISTING AND DESIRED AIR-TO-GROUND RADAR MODES

Air-to-Ground Modes	Aircraft Types										
	F-18	F-16	F-15	F-111A	F-111D	F-111E	F-111F	FB-111	F-4E	F-106	B-52
Ground Mapping	X	X	X	X	X	X	X	X	X		X
• Spoiled Beam	X				X						
• Real Beam	X	X		X	X	X	X	X	X		X
• High Resolution	X	X	GP	D	X	D	D	D	D		D
•• Doppler Beam Sharpening	X	X	GP		X						
•• Synthetic Aperture Radar	X										
• Freeze	X	X		D	X	D	D	D	D		D
• Expand	X	X			X						
Air-to-Ground Ranging	X	X	X	X	X	X	X	X	X		
Ground Moving Target	X	GP	GP	D	X	D	D		D		
• Fast Moving Target	X	GP	GP								
• Slow Moving Target	X	GP	GP								
Fixed Target Track	X	GP	GP	D	X	D	D	D	D		D
Ship Detection and Track	X	X		D	D	D	D	D	D		D
Navigation Update	X	X	X	X	X	X	X	X	D		X
• Position	X	X		X	X	X	X	X	D		X
• Velocity	X	D	X	D	X	D	D	D	D		D
Terrain Avoidance	X	GP	D	X	X	X	X	X	D		X
Terrain Following	X	GP	D	X	X	X	X	X			D
Special Modes											
Beacon	X	X	X	X	X	X	X	X	X		X
ECCM	X	GP	X	GP	X	GP	GP	GP	GP		GP
TV			X								
SNIFF			X								

E = Existing.
GP = Growth potential (possible with present hardware).
D = Desired (requires new hardware).

PRESENT AND PROJECTED A/C RADAR MODES

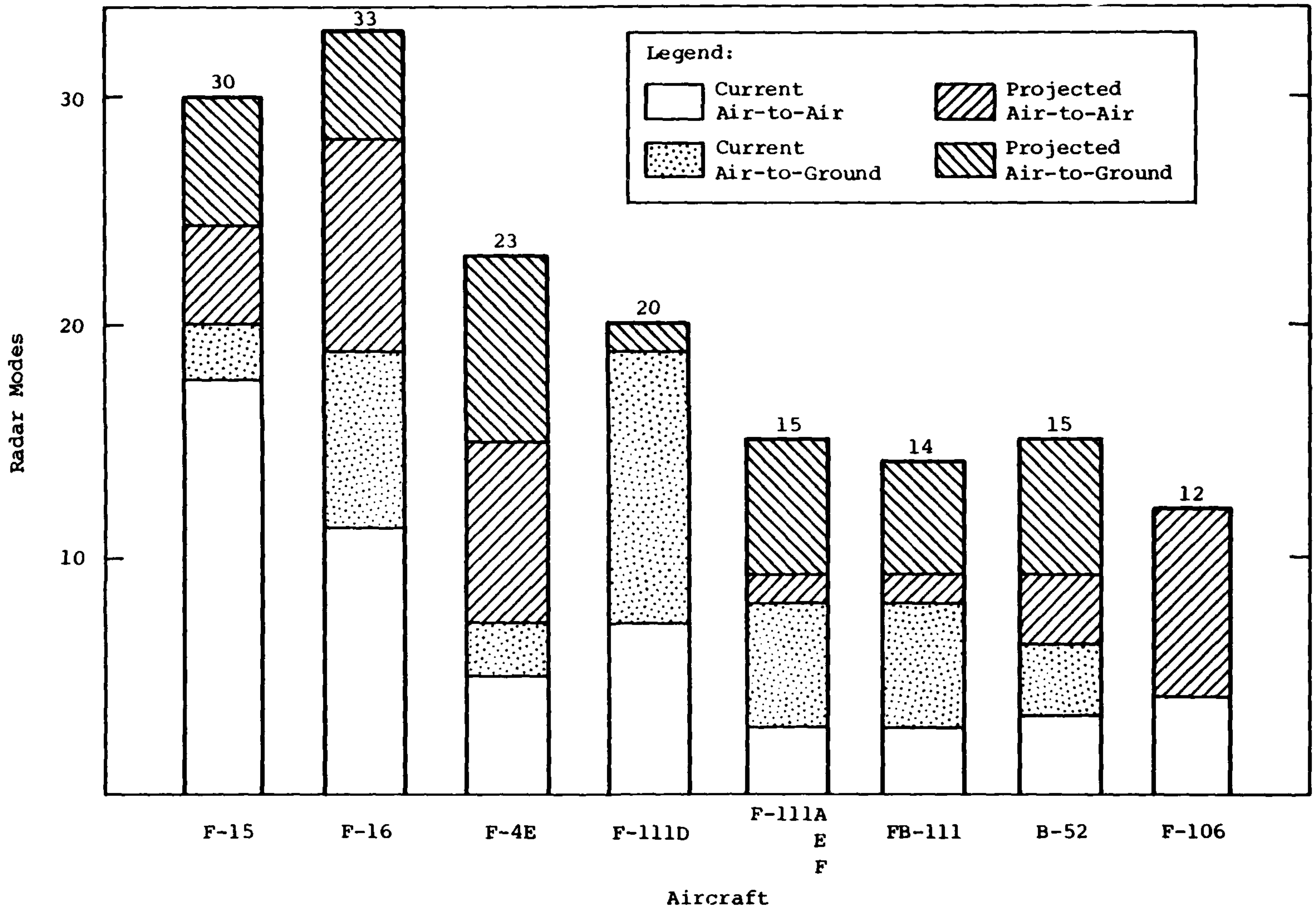

Figure 2-1. PRESENT AND PROJECTED AIRCRAFT MODES

Table 2-5. AIRCRAFT/WEAPONS COMPATIBILITY						
Air-to-Air Armament	Aircraft Series					
	F-18	F-16	F-15	F-111	F-4	F-106
Gun	X	X	X	X	X	
AIM-4						X
AIM-7	X	GP	X		X	
AIM-9	X	X	X	X	X	
AMRAAM	GP	D	D			

X - Compatible
GP - Growth potential (possible with present hardware)
D - Desired (requires new hardware)

Sidewinder is a short-range infrared heat-seeking missile that requires the target to be within a specified envelope. Processed radar returns determine when a target is within the AIM-9 envelope. The AMRAAM is discussed in Subsection 3.3.8 of this report.

2.5 CURRENT RADAR MODIFICATION PROGRAMS

The advances in radar technology, coupled with the reduced reliability of aging equipment used on most of the aircraft listed in Table 2-1, have resulted in the formulation of a number of radar modification programs for specific aircraft types. These programs have been intended to modify the radars to either increase the MTBF, increase the operational capability of the aircraft, or both.

2.5.1 F-106 Aircraft

The age of the F-106 aircraft and the tube technology used in the MA-1 radar system contribute to the low radar MTBF of 2.2 hours. In addition, replacement parts are difficult to obtain. To keep the F-106 viable, the Radar Upgrade and Modernization Modification (RUMM) Program has been proposed and is awaiting action by Air Force Headquarters.

RUMM is designed to improve existing radar equipment through the use of radar technology and hardware developed for other aircraft. The major reason for modifications is to improve reliability, maintainability, and supportability. A sole-source Class IV modification program is proposed, which means the modification would provide no increased capability in the aircraft. The F-106 would retain the armament currently available to it.

The RUMM program calls for replacing the hydraulically tuned transmitter entirely with an electronically tuned one and 30 of the 55 MA-1 LRUs. It would use modules from the F-15 APG-63 and mechanical parts from the F-18 APG-65 antenna. In addition to RUMM, a $16 million program to modify radar receivers is scheduled to begin installation in fiscal 1980 as a result of supportability problems with the older receiver.

2.5.2 B-52/FB-111 Aircraft

Modifications for operational reliability improvements are being considered for radar equipments of both the B-52 and FB-111 aircraft. To facilitate operations, the Strategic Air Command (SAC) is seeking improvements in terrain-following, terrain-avoidance, weapons-delivery and ECCM capabilities. Reliability improvements are necessary in existing radars because of their low MTBF.

The B-52 aircraft Phase I radar modernization plans, as outlined in the SAC letter of 11 October 1979 from ASD/SACSO to ASD/AERW, call for complete replacement of radar components with the exception of some power supplies and the antenna. Phase II of the Offensive Avionics System (OAS) modernization calls for replacement of current radar equipment not modernized during Phase I.

FB-111 modernization plans concentrate on improving ECCM capabilities for the terrain-following radar. These plans will depend on the results of the continuing ECCM Radar Improvement Program (ERIP) technology efforts discussed in the next chapter of this report.

2.5.3 F-4 Aircraft

There is presently no formal requirement to upgrade the F-4 radar nor are there any on-going modernization programs. McDonnell Aircraft Company has submitted Engineering Change Proposal (ECP) 7326 for an update of the avionics equipment and radar. The ECP is intended to increase the radar MTBF, improve performance, and reduce the support costs by eliminating flight line aerospace ground equipment (AGE).

2.5.4 F-111 Aircraft

The F-111 series aircraft have two proposed programs for different aircraft types. There is a $16 million plan to replace the synchronizer in the F-111F with a synchronizer developed for the B-1 aircraft to reduce support costs. The F-111D aircraft has five ECPs (estimated cost: $27,400,000) proposed to improve the overall performance of the APQ-130 radar.

2.5.5 F-15 Aircraft

The F-15 aircraft is currently in a radar modernization program to achieve operational improvements through software changes in its new programmable signal processor (PSP). This program is discussed in detail in Subsection 3.3.1 of this report.

2.5.6 F-16 Aircraft

Methods are being investigated to allow the F-16 to use the latest advances in radar technology to achieve operational improvements in both the air-to-air and air-to-ground capabilities of the aircraft. Accordingly, PSP software improvements for the F-16 are being pursued under the Fighter/Inteceptor/Strike/Technology (FIST) program discussed in Subsection 3.3.1 of this report.

Three additional funded programs other than FIST for the F-16 have been (1) a study by General Dynamics to investigate the effect of a total change in the aircraft radar, (2) a study by Westinghouse to investigate ways to improve the current F-16 radar through development of a new PSP and dual transmitter for increased range, and (3) a support contract performed by Technology Services Corporation to develop advanced radar performance and test specifications. In addition, the present F-16 production radar is currently undergoing its third major engineering change.

2.6 SUMMARY

There is a spectrum of current or planned initiatives to overcome radar deficiencies and improve performance of the radar systems presently installed in the candidate aircraft being proposed for the CMMR program. Appendix A provides a general overview of the basic principles underlying the design and implementation of these initiatives. The next chapter presents our review of existing Air Force technology programs relevant to these efforts.

CHAPTER THREE

TECHNOLOGY SYNCHRONIZATION

3.1 INTRODUCTION

There are approximately 15 current or planned Air Force advanced and engineering development programs to investigate aspects of radar technology that appear relevant to CMMR. Because the CMMR design must meet the requirements of a broad spectrum of users, the development of hardware and software for a CMMR will also involve much of the same technology as some of these other Air Force radar development efforts. The purpose of this chapter is to examine selected Air Force programs in order to highlight possible duplication of efforts, to investigate the feasibility of combining programs, and to suggest alternatives for timely transfer of technology to the CMMR program. After a brief discussion of each of the programs reviewed, a summary of the schedules, funding, technology outputs, and recommendations is provided.

3.2 ASSUMED SCENARIO

The CMMR development schedule used in this chapter forms the basis for many of the suggestions concerning the timing of other programs that provide needed technology inputs for CMMR. For the purpose of the analysis we assumed that the CMMR would be procured from the winner of an ASD proposed dual-source competition using the F-16 aircraft as a test bed. The schedule requires that design, fabrication, and integration of both competing systems be completed by 1 April 1981. This schedule is ultimately driven by an F-16 effectivity requirement for fiscal 1984. One design alternative is a modification to the existing F-16 radar LRUs with a PSP (CMMR-compatible in size, throughput, etc.) and a new dual mode transmitter with a high pulse repetition frequency (PRF) mode for increased nose aspect detection range, both developed by Westinghouse. The other primary alternative, the Hughes entry, would be a derivative of the F-18 APG-65, which ASD indicates is presently compatible with CMMR requirements, slightly modified for F-16 use. The general characteristics of these two designs are provided in the last chapter.

3.3 CMMR-RELATED PROGRAMS

The programs discussed in this section all involve some aspect of development that is also required by the CMMR Program. The technology interfaces are discussed and program changes are suggested in those cases where technology synchronization appears to be more cost-effective.

3.3.1 P.E. 64201F/2519 -- Radar PSP Technology

Program Element 64201F, Project 2519, contains funding for both the Fighter/Interceptor/Strike/Technology (FIST) Program managed by the F-15 SPO and the F-16 program. The main objective of this project is to design and test improved PSP software for numerous air-to-air and air-to-ground missions. The F-15 APG-63 radar will be used to demonstrate this capability. Project 2519 is also intended to establish the practicability of using common PSP software and hardware in F-16, F-4, B-52, F/FB-111, and F-106 aircraft. In conjunction with this second objective, the project specifically provides for the design and test of F-16 PSP software enhancements for air-to-air and air-to-ground application. To ensure program continuity, a new PSP has been developed for the existing APG-63 radar and is being acquired from Hughes by the F-15 SPO under ECP 937. Production units of this PSP are scheduled to be introduced into the fleet beginning in May 1980.

The FIST program is a three-phase effort. Phase I, which is of primary interest to the CMMR program at this time, includes development and demonstration of software changes to the new F-15 production PSP, flight demonstration of other hardware and software improvements, and studies related to common users of these improvements. Phase II involves development of new PSP-related hardware to demonstrate additional air-to-ground modes. Phase III involves aircraft and radar modifications to both the F-15 and F-16.

The Phase I effort includes two tasks. The first develops and demonstrates new PSP software, and the second demonstrates the software improvements and associated new hardware. As mentioned above, the APG-63 PSP will be used to develop and test in flight the software to provide for additional radar modes. The software modes to be demonstrated under Phase I, Task 1, are the following:

- Track While Scan (TWS) - adds capability for detecting and tracking multiple targets
- Long-Range Search (LRS) - extends the effective range of the radar for rear hemisphere detection
- Passive Ranging - provides capability for measuring range to jamming targets in both the electro-optic (EO) and microwave portions of the spectrum without actively transmitting
- Raid Assessment Mode Electronic Counter-Countermeasures (RAM ECCM) - develops algorithms to aid in target sorting in an ECM environment while the radar is in the raid assessment mode.

Under Phase I, Task 2, new PSP-related hardware and software are being developed by the Air Force. In the meantime the contractor with independent research and development (IR&D) funds is modifying the existing APG-63 for a synthetic aperture radar (SAR) demonstration. Figure 3-1 illustrates the complexity SAR adds as compared to the APG-63 PSP radar. This new equipment will be loaned to the Air Force in support of Task 2 to develop and demonstrate added air-to-air software. The following modes are to be demonstrated under Phase I, Task 2:

- Non-Cooperative Target Recognition (NCTR) - target signature recognition by PSP analysis of reflected energy (high PRF nose aspect capability)
- Improved TWS/RAM Displays - will include a programmable symbol generator
- Improved ECCM - frequency agility routine, improved channelization, and other enhancements

Software documentation developed during the FIST Program, which includes algorithms, program logic, flow charts, and any memory or timing limitations for software modules procured by the F-15 SPO from the contractor, is to be forwarded for use by the F-16 SPO and other interested program offices.

As presently scheduled, the software developed during Phase I, Task 1, of the FIST Program could not be transferred to the F-16 SPO until after flight test in the third quarter of fiscal 1981. This schedule does not provide the new software modes to the F-16 CMMR Program in time to be of value. An alternative is that the software be transferred to the F-16 SPO after development by the contractor, with sufficient lead time to allow participants in the F-16 competition to integrate the algorithms into their hardware prior to flight testing scheduled to begin in the second quarter of fiscal 1981.

The NCTR algorithms present an additional timing problem, since they are not scheduled to be provided to the FIST Program until the beginning of the third quarter of fiscal 1981. This would not provide sufficient time to code these algorithms into the F-16 competing PSP designs to permit flight test of the NCTR mode before the source selection scheduled for October 1981.

3.3.2 P.E. 63742F/1177 -- NCTR

NCTR technology is being developed by the AFAL under P.E. 63742F, Project 1177. Under this program, air-to-air data will be collected and recorded using the F-15 test-bed aircraft just mentioned. These data will then be played back at the contractor's facility through an engineering model of the PSP programmed with the appropriate identification algorithms. Requirements for integration of the NCTR algorithms into a "real world" multimode programmed PSP will be examined during the data collection and validation phases. The data collection phase is planned to occur during

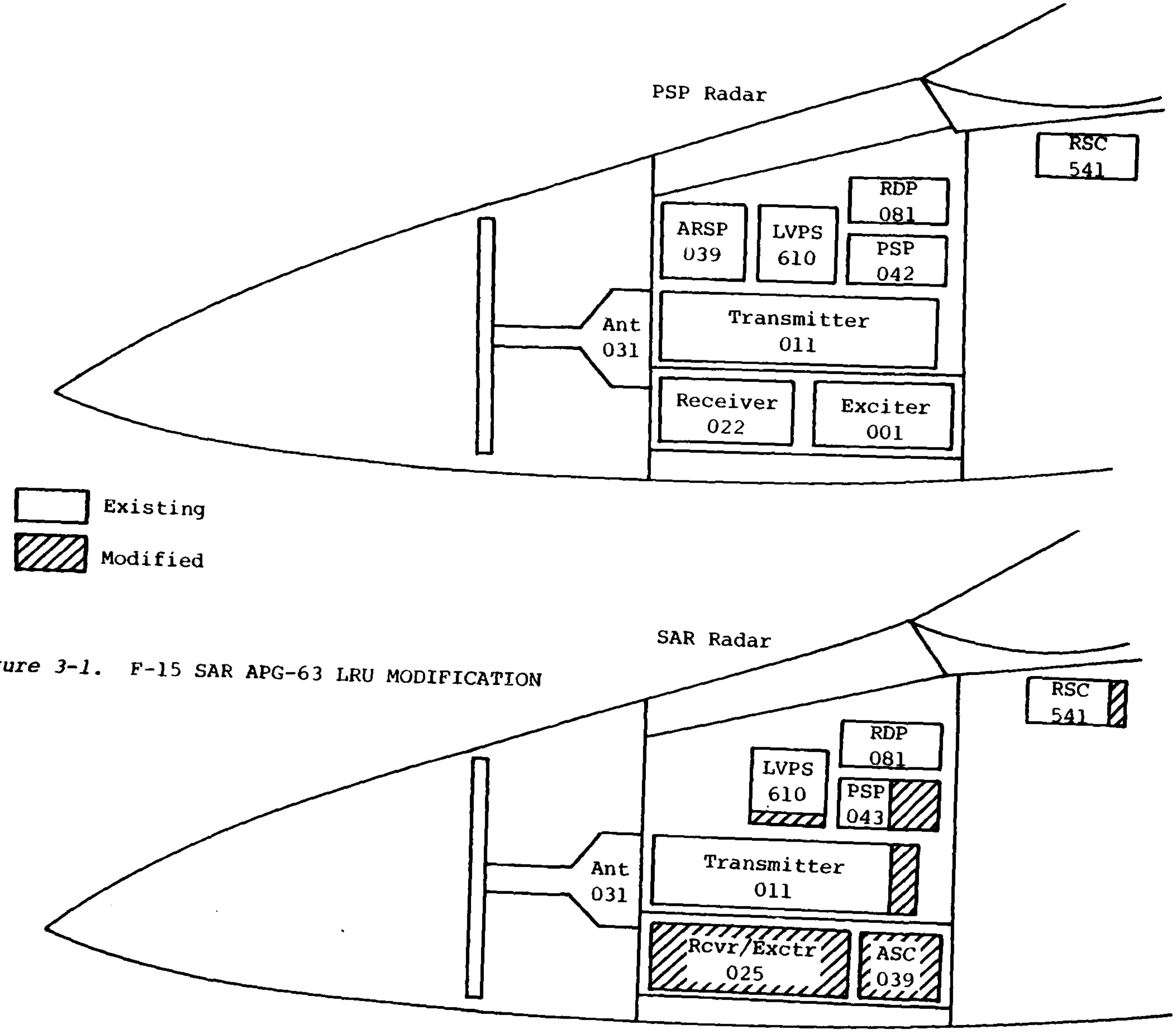

Figure 3-1. F-15 SAR APG-63 LRU MODIFICATION

the third and fourth quarters of fiscal 1980. The validation phase is planned to occur during the first and second quarters of fiscal 1981. The results will then be provided to the F-15 SPO in the form of software algorithms and data relative to performance limitations. We recommend that the NCTR technology be accelerated by six months to meet the requirement discussed in the previous subsection.

3.3.3 P.E. 63203F/69DF -- ASRAT

The Advanced Strike Radar Technology (ASRAT) Program is a software development effort conducted by the Air Force Avionics Laboratory (AFAL) to replace the terminated All-Weather Tactical Strike System (AWTSS) Program. It is intended to demonstrate the critical radar technology needed to fulfill the requirements outlined in the Advanced Tactical All Weather Strike (ATAWS) General Operational Requirement (GOR). These requirements include the capability to autonomously detect and locate fixed and moving targets with a minimum aircraft exposure profile during targeting. The system must be compatible with existing and currently planned weapons. Additionally, defense neutralization must be provided through ECCM, terrain following/terrain avoidance, and passive/active emitter radio frequency (RF) cueing.

In the near-future (fiscal 1980 and 1981) ASRAT will address the technologies of slow moving target indication/location (MTI/L) and RF cueing. The method proposed by ASRAT to solve the slow MTI/L problem is a technique in which the slow-mover is coherently detected by a SAR. Post-detection manipulation of the SAR-generated map is then used to relocate the doppler-displaced moving target to its true relative position. The RF cueing problem is complicated by the angular error at low flight elevations resulting in large range uncertainty. The proposed near-term solution to this problem is the Texas Instruments' Multi-Purpose Radar/Missile Site Location System (TIMPR/MSLS). Flight demonstrations of the MTI/L capability may not be completed until mid-to-late fiscal 1981, depending upon which test-bed aircraft is used. The TIMPR/MSLS capability is scheduled for flight test between the third quarter of fiscal 1980 and the second quarter of fiscal 1981. Neither of these schedules will permit integration of this capability into the CMMR F-16 competitive test aircraft.

The ASRAT far-term technology program includes development of multimode terrain following/terrain avoidance (TF/TA), air-to-ground ECCM, and advanced weapon delivery technology. ASRAT will assess the multimode fighter radar TF/TA function. This will involve determination of antenna mechanical suitability, evaluation of closed-loop automatic TF/TA with existing flight control systems, selective redundancy, and signal processor requirements planned for flight testing during fiscal 1983 and 1984. Advanced weapon delivery technology efforts are programmed for the fiscal 1983 to 1984 time frame. This involves delivery of launch, leave, and forget weapons such as the wide area anti-armor munition (WAAM) and WASP.

Since both the near-term and mid-term results of ASRAT could be included directly in CMMR to satisfy basic CMMR requirements, merging the two programs should be considered. The near-term output of ASRAT as now

structured will not be responsive to the proposed CMMR competitive test program. With a combined program, MTI/L and TIMPR/MSLS could be tested on the F-16s during the CMMR fly-off. A disadvantage of this approach would be the integration of ASRAT technology into two different radar/PSP designs with the attendant risk of a competitive flight test program using unproven software. However, the accelerated availability of the technology and the ability to evaluate each CMMR candidate with these capabilities added appear to outweigh these disadvantages.

3.3.4 P.E. 63249F/2963 -- LANTIRN

Program Element 63249F, Project 2963, Low Altitude Navigation Targeting Infrared for Night (LANTIRN), was established to provide the tactical air forces an improved 24-hour capability to acquire, track, and destroy ground targets with a single-place aircraft. The solution is to provide this capability by developing an autonomous pod to be used with F-16 and A-10 aircraft. It would be an under-the-weather system employing forward-looking infrared (FLIR) target acquisition, manual TF, and automatic target recognition of ground targets through IR characteristics. The primary weapon to be used with the system is the IR Maverick missile. The system would also contain a 1.06-micron laser for use with laser-guided bombs employed against large fixed targets.

The system is designed to provide an interim capability for timely deployment to the tactical air forces. As an under-the-weather system only, it does not provide the full adverse-weather capability nor closed-loop automatic TF/TA (to be provided by the ASRAT program).

In the TF/TA area, LANTIRN and ASRAT have a common interest, albeit at different levels of sophistication.

To develop an interim capability, the first LANTIRN production hardware is planned to be available in December 1983. System Initial Operational Capability (IOC) is currently scheduled for fiscal 1984. ASRAT TF/TA flight testing is scheduled for completion in the first quarter of fiscal 1984, and assuming the first F-16 retrofit is completed 18 months after flight test, an IOC in the second quarter of fiscal 1986 appears feasible. Under these schedules, LANTIRN could provide an interim manual TF/TA capability for up to two years before the fielding of the ASRAT-developed automatic system. Given the flight safety aspects of automatic flight control integration with TF/TA, the first quarter of fiscal 1984 may be optimistic for development, integration, and validation of an automatic closed-loop ASRAT TF/TA system. Because of this, any dates for automatic TF/TA development should be considered as "not earlier than."

3.3.5 P.E. 64201F/2259 -- ERIP

Program Element 64201F, Project 2259, ECCM Radar Improvement Program (ERIP), was established to improve the ECCM capability of selected airborne radars in the near future. As a combined result of this ASD/AE program and ECCM testing of F-111 radar systems under the AFAL Coronet Buzz program, deficiencies in the F/FB-111 radars were identified and

corrective actions recommended. These included design changes to the TF/TA radar transmitter, receiver, and antenna. Current and future efforts under the ERIP program are scheduled through fiscal 1985. F-111 radar modifications and flight tests are planned during fiscal 1980 through 1982. During fiscal 1982 through 1985, F-106, C-130, and F-4 ECCM deficiencies will be identified and fixes will be tested.

It appears feasible that the hardware and software design for the CMMR TF/TA modes could incorporate the results of the ERIP and the Coronet Buzz efforts for the F/FB-111. Aircraft that become firm candidates for the CMMR program and that are also included in the ERIP program could be dropped from the ERIP and absorbed into the CMMR program.

3.3.6 P.E. 63205/2506 and P.E. 63245/2061 -- AFTI

Under the F-16 Advanced Fighter Technology Integration (AFTI) Program (P.E. 63205, Project 2506 and P.E. 63245, Project 2061), advanced development leading to an Integrated Fire and Flight Control (IFFC) system demonstration in an F-16 aircraft is being performed by the Air Force Flight Dynamics Laboratory (AFFDL). The goal of the IFFC system is to provide a capability to maneuver the F-16 aircraft while the weapon system is attacking ground targets in order to provide a significant increase in survivability against targets defended by AAA. This program is intended to double the accuracy in delivery while maneuvering as compared to manual control. Additionally, for air-to-air weapon delivery, the IFFC is expected to provide a threefold increase in gunnery hits and improved missile exchange ratios over the baseline F-16 by reducing operator workload.

This work is being accomplished under an AFFDL contract with General Dynamics and is divided into two phases. The present initial phase is developing the Digital Flight Control System (DFCS) for the test aircraft. This system is scheduled for a nine-month flight test beginning in July 1981. The second phase involves the development of the overall IFFC system, which then ties the flight control system to the fire control system using a digital IFFC processor. The IFFC system will require a two-year advanced-development effort presently scheduled to begin in July 1980. Following IFFC developmental flight testing late in 1982, a demonstration flight program is scheduled for the third quarter of fiscal 1983 at Nellis AFB.

The development of the DFCS portion of the IFFC System should be closely coordinated with the ASRAT Program because of the potential need for an interface between the DFCS and an ASRAT-developed automatic closed-loop TF/TA system in the 1982 to 1984 time frame. The CMMR radar development should consider a capability for short-range track to provide director information to the IFFC in the air-to-air mode.

3.3.7 P.E. 63747F/2217 -- Assault Breaker (PAVE MOVER)

Assault Breaker (AB) is a joint Air Force, Army, and Defense Advanced Research Projects Agency (DARPA) program to develop the capability to attack mobile, rear-echelon armor arrays day and night and in adverse

weather. Program Element 63747, PAVE MOVER, established the Air Force program in support of AB. The responsibility for the technology development for the AB radar has been assigned to the Electronic Systems Division of AFSC. Project 2217, PAVE MOVER Target Acquisition Weapon Delivery System (TAWDS), is designed to develop MTI radar technology for all-weather, long-range (stand-off) detection of slow moving and fixed ground targets from fixed wing aircraft. The program has been established to demonstrate that the TAWDS can locate such targets using data from an MTI radar with sufficient accuracy to provide real-time weapon guidance against multiple targets in a designated area.

Dual contracts have been awarded to Grumman Aerospace Corporation and Hughes Aircraft Company to design, develop, test, and evaluate advanced development models (ADMs) of the PAVE MOVER/TAWDS. The TAWDS employs an airborne side-looking X-band radar with a large (approximately three meters) electronically steerable antenna. It contains integrated features for low probability of intercept (LPI) and jam resistance. The processor associated with this system will be ground based. The radar system will be capable of wide-area surveillance of moving targets, surveillance of multiple small areas in which both stationary and slow moving targets can be tracked, and single platform range/angle real-time precision guidance of multiple weapons and manned aircraft. It is to perform these functions in an interleaved fashion during adverse weather, in day or night conditions at long ranges.

The key objectives of the TAWDS program are to evaluate data on target scatter statistics, terrain and foliage shadowing effects, rain and other weather effects, range and angle measurement accuracy, and minimum detectable target velocity. Other objectives are to evaluate system tradeoffs related to target track accuracy, weapon track and guidance update rate, unambiguous range after processing, surveillance scan time, and LPI/ECCM performance.

Both the Grumman and Hughes systems are being developed and fabricated; they are scheduled to be completed in the fourth quarter of fiscal 1980. Flight testing is scheduled to occur from the fourth quarter of fiscal 1980 to the third quarter of fiscal 1981. Current MITRE Corporation engineering development model studies are scheduled for completion in the fourth quarter of fiscal 1981. Radar technical support is being provided by the Lincoln Laboratory and AFAL. This support is also scheduled for completion in the fourth quarter of fiscal 1981.

The technical objective of the PAVE MOVER/TAWDS program is to evaluate an advanced development model SAR employing coherent doppler processing. As mentioned previously, SAR MTI technology is being pursued under the ASRAT program for possible application to CMMR. While TAWDS does not have a direct applicable interface with the CMMR program, close coordination should be maintained between the TAWDS and ASRAT managers to provide maximum technology synergism and to ensure against duplication of subtasks.

3.3.8 P.E. 633701/2437 -- AMRAAM

The Advanced Medium Range Air-to-Air Missile (AMRAAM) Program is driven by a joint services operational requirement. The program, managed by a joint SPO located at Eglin Air Force Base, has been established to provide a multiple air-to-air missile launch capability (assuming the aircraft radar is capable of multiple target track) for the F-14, F-15, F-16, and F-18 aircraft. The AMRAAM will use rail launchers, and its design should provide total compatibility with all four of those aircraft. The F-16, if outfitted with AMRAAM, would also maintain its capability to carry current missiles. The AMRAAM missile complement for the F-16 would vary; it would depend on particular mission requirements. It is now envisioned that as many as six AMRAAM missiles could be carried on any given mission.

The avionics functions required by the missile can be divided into three phases: prelaunch, launch, and postlaunch. All prelaunch and launch instructions [launch zone computations, missile initialization, built-in-test (BIT)] are provided to the missile from the F-16 fire control computer (FCC). Data provided to the missile will be in MIL-STD-1553 format. Preterminal instructions (midcourse corrections) are handled by both the aircraft and missile computers and transmitted to the missile in flight. Terminal guidance is provided by the missile's X-band radar guidance subsystem or home-on-jam (HOJ) capability.

Hughes and Raytheon are presently in AMRAAM validation-phase competition. The winner of this competition will be selected at the end of fiscal 1981, at which time full-scale engineering development will begin. The first production units should be available at the end of fiscal 1985.

The CMMR design must be responsive to the data requirements of AMRAAM and should not limit the operational capabilities inherent in AMRAAM. CMMR must be able to search for and track multiple targets simultaneously and to designate targets beyond visual range to take full advantage of the AMRAAM capabilities. The winner of the Hughes-Raytheon competition will not be known until the fourth quarter of fiscal 1981, which is too late to influence CMMR design before CMMR source selection. Therefore, the Hughes and Westinghouse CMMR designs must be compatible with both competing Hughes and Raytheon midcourse update concepts proposed for AMRAAM.

3.3.9 P.E. 63241/1206 -- EAR

The Electronically Agile Radar (EAR) developed for the B-52 by Westinghouse is a multimode radar employing a programmable signal processor and an electronically scanned antenna. Although the EAR Program has been completed, it is included here as a potential source of technology relative to multimode radar programmable signal processing. Modes presently available with the EAR PSP are a 20-foot resolution SAR Map, Doppler Beam Sharpening (DBS) Map, TF/TA, Real Beam Ground Map, Freeze, and Navigation Position and Velocity Update. Because the EAR PSP is presently configured to provide the above modes in conjunction with an electronically scanned

antenna, it would require software modification for interface with the present F-16 mechanically scanned antenna.

3.4 SUMMARY

The radar technology programs reviewed in this chapter need to be synchronized in order to provide the most cost-effective and timely implementation of the CMMR Program. Figure 3-2 and Table 3-1 summarize the programs, their schedules, and their anticipated results and suggest several changes. The CMMR Program can make use of the results of several programs; however, in many other cases the project feeding CMMR is not scheduled to meet the F-16 effectivity date. As Table 3-1 shows, the majority of the near-term data required by the CMMR Program in 1980 is in the form of software algorithms. Under the present schedules, it is possible to transfer most of these algorithms (in unvalidated form) to the CMMR Program for checkout and test during the proposed F-16 dual flight test program in fiscal 1981. Two exceptions are the tests of the MTI/L and NCTR modes, which would require 3-month and 6-month accelerations, respectively.

Another potential program feeding near-term technology into the CMMR effort is PAVE MOVER (P.E. 63747F/2217). This program could provide data concerning SAR MTI technology of potential value to the ASRAT MTI/L effort.

Funding profiles are provided in Table 3-1 to indicate the magnitude of the effort. The funds shown are for the total program element/project and not only for the technology outputs shown. Additional funding will be required to ensure timely technology transfer to the CMMR Program. Table 3-2 provides a schedule for actions that can be taken.

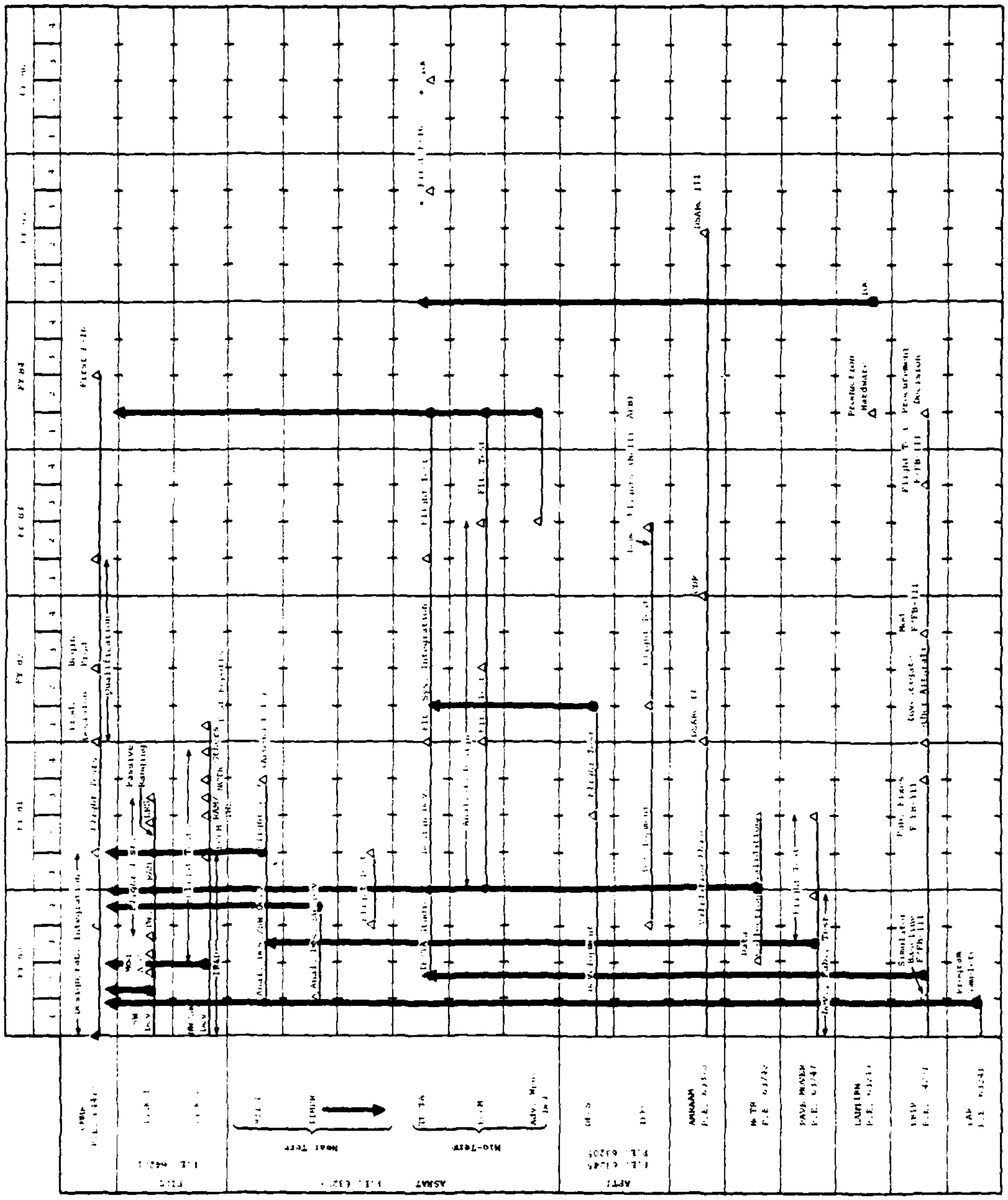

Figure 3-2. PROGRAM SCHEDULES FOR CMMR-RELATED TECHNOLOGY EFFORTS

Table 3-1. FUNDING PROFILE OF CMMR-RELATED TECHNOLOGY OBJECTIVES

Program/Project	TWS	RAM	NCTR	RF Cueing	SAR/DBS	GMTI/S (Slow)	TF/TA (Auto)	LRE	Passive Ranging	A/C ECCM	Advanced Weapon Detection	Millions of Dollars, from 14 SEP 1979 BES basic: FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	Program Completion Date	Date Technology Required by CMMR	Technology Output
64201/2519 (RESP)	X											6.5	9.5	6.8	9.9	9.6	3.7	Sep 1980	Sep 1980	Software Algorithms
Subtask		X																Dec 1980	Sep 1980	Software Algorithms
Subtask								X										Jun 1981	Sep 1980	Software Algorithms
Subtask									X									Mar 1981	Sep 1980	Software Algorithms
63742/1177 (NCTR)			X									2.1	3.6	4.1	4.4	2.9	2.9	Apr 1981	Sep 1980	Software Algorithms
63203/69DF (ASRAT)				X								7.4	8.6	10.8	14.1	15.0	15.9	Jan 1981	Sep 1980	Software Algorithms
Subtask						X												Aug 1981	Sep 1980	Software Algorithms
Subtask							X											Jan 1984	Mid 80s	Software, Hardware
Subtask										X								Jan 1984	Mid 80s	Software, Hardware
Subtask											X							Jan 1984	Mid 80s	Software, Hardware
63249/2693 (LANTIRN)												31.3	17.1	16.1	7.6			Dec 1983	*	Hardware
64201/2259 (ERIP)										X		2.8	3.0	2.5	4.0	5.0	3.0	Through 1985	FY 81**	Software, Hardware
63245/2061 (AFTI) 63205/2506							X X					5.2 8.2	4.7 7.5	4.7 8.5	4.0 7.6	1.4 8.4	11.9	Mar 1983	1982 1984	Software, Hardware
63747/2217 (PAVE MOVER)						X	X					6.7	13.1	5.0	18.4	8.2	3.4	Mar 1981	Sep 1980	Data
63170/2437 (AMRAAM)†	X	X	X										7.5	8.3	12.5	5.5		Sep 1981 DSARC II		
63241/1206 (EAR)					X		X			X								Complete		Software, Hardware

*Interim manual TF/TA capability until CMMR automatic TF/TA capability is developed; no technology transfer to CMMR program.
**F-111/Coronet buzz data to TF/TA development (PE 63203/69DF).
†Funds shown are for Class V Modification.

Table 3-2. TECHNOLOGY PROGRAMS REVIEWED

Title	Program Element/Project	Remarks
Radar Programmable Signal Processor (RPSP)	64201/2519	Transfer software to F-16 as soon as possible
Non-Cooperative Target Recognition (NCTR)	63742/1177	Accelerate program and transfer software to F-15 as soon as possible
ECCM Radar Improvement Program (ERIP)	64201/2259	Transfer applicable portions to CMMR
Advanced Strike Radar Technology (ASRAT)	63203/69DF	Combine program with CMMR
Advanced Fighter Technology Integration (AFTI)	63205/2506 63245/2061	Closely coordinate efforts with ASRAT; develop CMMR to be compatible
Low Altitude Navigation Targeting Infrared For Night (LANTIRN)	63249/2693	Interim manual terrain-following system for F-16 and A-10
Assault Breaker (PAVE MOVER)	63747/2217	Closely coordinate efforts with ASRAT
Advanced Medium Range Air-To-Air Missile (AMRAAM)	63370/2437	Develop CMMR to be compatible
Electronically Agile Radar (EAR)	63241/1206	Programmable Signal Processor (PSP) software is potential technology source for CMMR

CHAPTER FOUR

TRADE-OFF AND RISK ANALYSES

4.1 INTRODUCTION

Our trade-offs are based on both qualitative and quantitative analyses of tasks identified by the ASD program office. Management considerations subjected to qualitative and quantitative risk and schedule analyses comprise the following:

- Sequential versus parallel CMMR developments
- LRU modular standardization versus system standardization
- Cost payback as a function of aircraft applications
- Competitive acquisition payoffs or penalties as a function of learning curve rates

4.2 MARKET ANALYSIS

4.2.1 Quantities of Radars Involved

The same candidate aircraft included in the ASD Study have been used here. Aircraft quantities were developed from the latest issue (October 1979) of the Avionics Planning Baseline. Table 4-1 lists the number of aircraft (thus potential CMMRs) for the force structure from fiscal 1980 to fiscal 1991. The aircraft numbers shown are for the end of the fiscal year and, except for the F-16, are decreasing due to attrition or phase-out. The B-52-G/H aircraft uses a single radar for both the bombing/navigation and the fire control systems; each B-52 will require two CMMRs to replace the present systems. Current Air Force planning for the F-106 shows it being phased out of the active inventory beginning in fiscal year 1990, with a drop of 83 during the fiscal year. The assumed market totals 2,414 units. The development of the assumed market is discussed more fully in Section 4.2.3.

The decreasing F-16 numbers that have been derived are not force structure quantities. The decrease indicates CMMR quantities "lost" because a CMMR was not available for a production aircraft. The number shown is based on a total production of 1,388 aircraft with a rate of 10 per month after aircraft number 650 (October 1983); the production schedule

Table 4-1. POTENTIAL CMMR MARKET BY FISCAL YEAR (APB OCTOBER 1979)									
Aircraft	Fiscal Year								
	1983	1984	1985	1986	1987	1988	1989	1990	1991
F-16 (Derived)	738	618	498	378	258	138	18	0	0
F-4	664	659	655	651	648	642	638	635	633
F/FB-111	371	367	360	357	351	350	345	339	336
B-52 (two per aircraft)	532	532	532	528	528	528	526	524	524
F-106	212	209	207	203	201	198	196	113	111
Total Radars	2,517	2,385	2,252	2,117	1,986	1,856	1,723	1,611	1,604

Assumed Market:

F-16	678	F-106	209	B-52	528
F-4	678	F/FB-111	351		

Total 2,414 (Does not include spares)

is based on guidance from the F-16 SPO. The number of CMMR units required does not include any that would be needed if the F-16 were to be retrofitted with common radars and also does not include spares.

Figure 4-1 shows the potential CMMR market at the end of each fiscal year. Note the change for the F-16 (both quantities and production rate) during fiscal 1982 in accordance with the guidance provided. The decreasing CMMR market is due almost entirely to the installation assumption in relation to the F-16 program.

4.2.2 Factors Affecting the Market

To make a broad analysis of the potential CMMR market and how it might change with time, and to gain some insight into necessary trade-offs, many factors must be considered, including the following:

- CMMR development, acquisition, and installation/integration costs for each aircraft application
- Anticipated initial CMMR production delivery date
- Production delivery rates of CMMRs
- Estimated reliability and logistic support costs for both existing radars and a CMMR with an MTBF of 50 hours
- Radar modification programs programmed or planned for existing radars

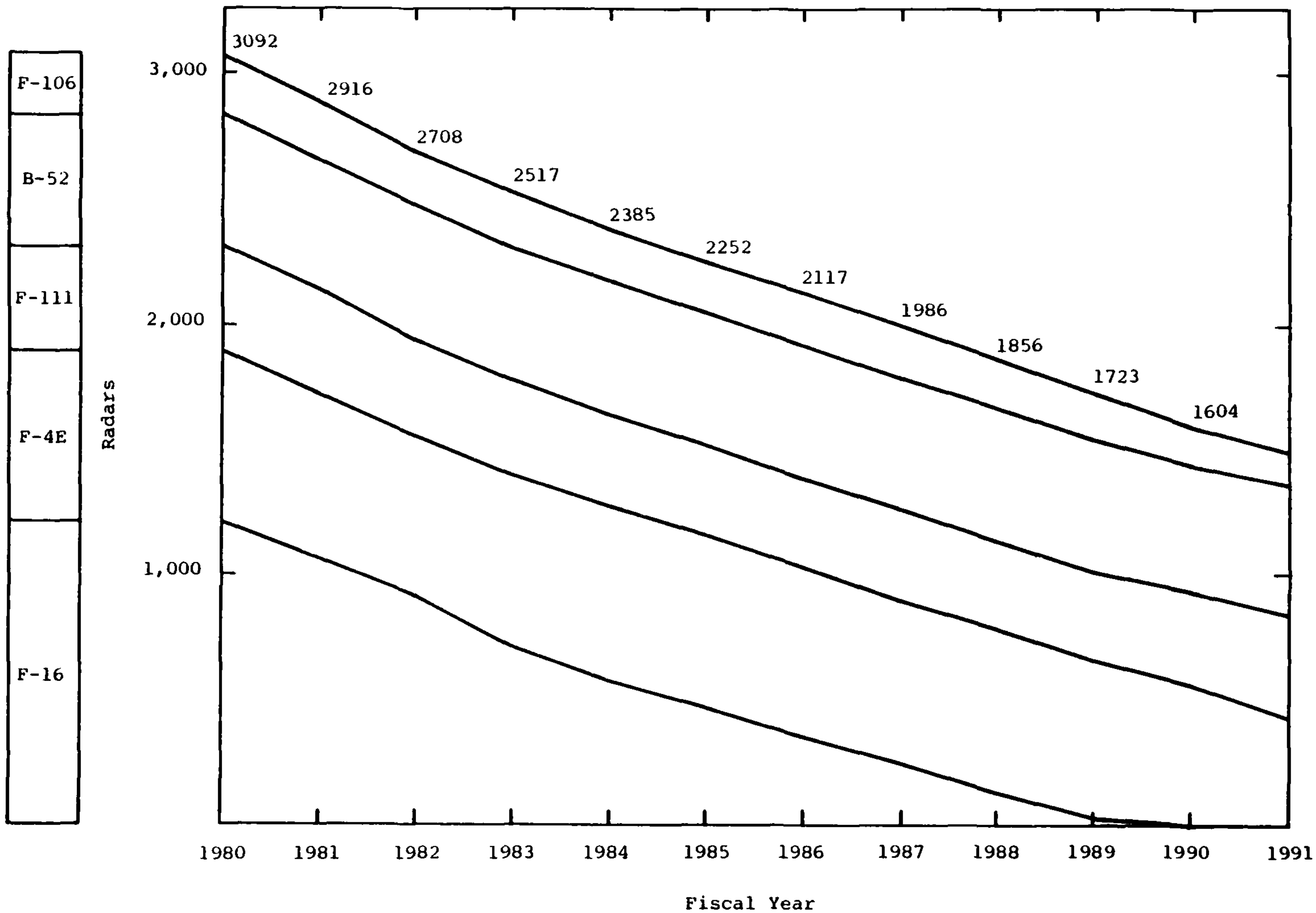

Figure 4-1. POTENTIAL CMMR MARKET

- Hypothetical anticipated force structure life of candidate aircraft under study

4.2.3 Hypothetical Installation Schedule

As an initial starting point for reviewing the installation schedule, it is assumed that the CMMR would not be available to the F-16 for approximately four years. This results from an assumption that a competitive development program and fly-off would be required. It would take the selected manufacturer time to build up to his maximum monthly production rates; thus an additional six months was allowed for initial delivery of radars for aircraft other than the top-priority F-16. Initial CMMR delivery dates were projected to be March 1, 1984, for the F-16 and October 1, 1984, for the remaining candidates. The resulting F-16 market used in the analyses is 678 (738 less 60 for the six months "lost").

Table 4-2 presents an installation schedule based on information provided by AFLC. Because of the pressing economic need for a new radar, the F-106 depot installation schedule was not used. Instead a field modification, similar to that proposed in the pending AFLC F-106 RUMM program, is postulated.

Table 4-2. AFLC PROJECTED INSTALLATION SCHEDULE

Aircraft Types	FY 82				FY 83				FY 84				FY 85				FY 86			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2		
F-4E*	28	32	28	35	31	34	28	32	25	29	26	25	34	40	37	34	24	24		
F-106**	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13				
F/FB-111**	30	30	28	23	36	24	19	26	23	29	28	34	18	22	24	31				
B-52**	15	16	15	16	15	16	15	16	15	16	15	16	15	16	15	16				
F-4E/G*	28	32	28	36	38	42	35	39	32	36	34	31	41	47	43	40	31	30		

*The installation schedule beyond the first half of fiscal 1986 for the F-4E and F-4E/G remains constant at 24 and 30 per quarter.

**The installation schedule beyond fiscal 1985 for F-106, F/FB-111, and B-52 will repeat in four-year cycles.

The following are the assumed average installation rates used in the market analysis for the aircraft under study, based on the information in Table 4-2:

- F-16, F-106, F-4: 10 per month
- F/FB-111: 9 per month
- B-52: 124 per year

To develop a hypothetical installation schedule, we gave first priority to the F-16. We derived the number of units of the CMMR that would be needed from the earliest possible time the units could be available for the F-16 production line. The F-106 was given second priority because of its pressing economic need; fiscal 1984 numbers were used in determining the quantities that would be needed. We then used fiscal 1987 numbers as "average" installation quantities for the B-52, F/FB-111, and the F-4. Using the installation rates assumed above, we could then approximate the length of time it would take to install CMMRs in the candidate aircraft, as shown in Figure 4-2. This projection does not consider any limits on production rates.

Figure 4-3 summarizes the demand for CMMRs as developed from the hypothetical installation schedule, supplying the top priority F-16 first, then the F-106, and the remainder with equal priority. It should be noted that for the present this demand does not consider spares that might be required. Superimposed on this plot is an indication of three postulated production build-ups of CMMRs for a single manufacturer (dotted lines), assuming no production impact to or from radars currently in production. Buildup quarterly production quantities used were 6, 12, 28, and 40 respectively. Two contractors indicated that their maximum capacity would be approximately 40 radars per month without new tooling, so it is evident that a single manufacturer can not meet the hypothetical schedule demands for the five candidate aircraft between fiscal 1985 and 1989.

4.3 CMMR PROGRAM COSTS

If the F-16 is used as a test bed for a new common radar rather than separate radar developments being pursued for each candidate aircraft, the ASD Common Radar Study showed a potential development cost savings of $208.4 million for the CMMR program (Table 4-3). With this information, other cost data contained in the ASD Study, and the force listed in Table 4-1, ASD investment and logistics support costs (LSCs) were revised for the six candidate aircraft models to be retrofitted. (The F-111, FB-111, B-52G, and B-52H were listed separately). The F-16 LSCs were assumed to be the same as those for a CMMR, since the radar would be provided as "in-line" aircraft production equipment. We did not attempt to relate this cost to the cost of the present F-16 radar RIW program.

Both the ASD Study cost data and ARINC Research cost data are summarized in Table 4-4. In each case the basic cost data (adjusted linearly for new force structures) are the same except for our F-16 radar unit cost data ($550,000), which was developed from the latest radar contractor information. Also, in the ASD Study FB-111 and F-111 costs were treated together. We have split these costs to handle the FB-111 and F-111 series separately.

The unique development costs, as provided by ASD, comprise Group A and B development, changes to support equipment, flight testing, and data. Integration and installation costs comprise kit proofing, Group A and B aircraft installation, and ECPs to modify other aircraft equipment as a result of the new radar. Logistic support costs comprise initial and

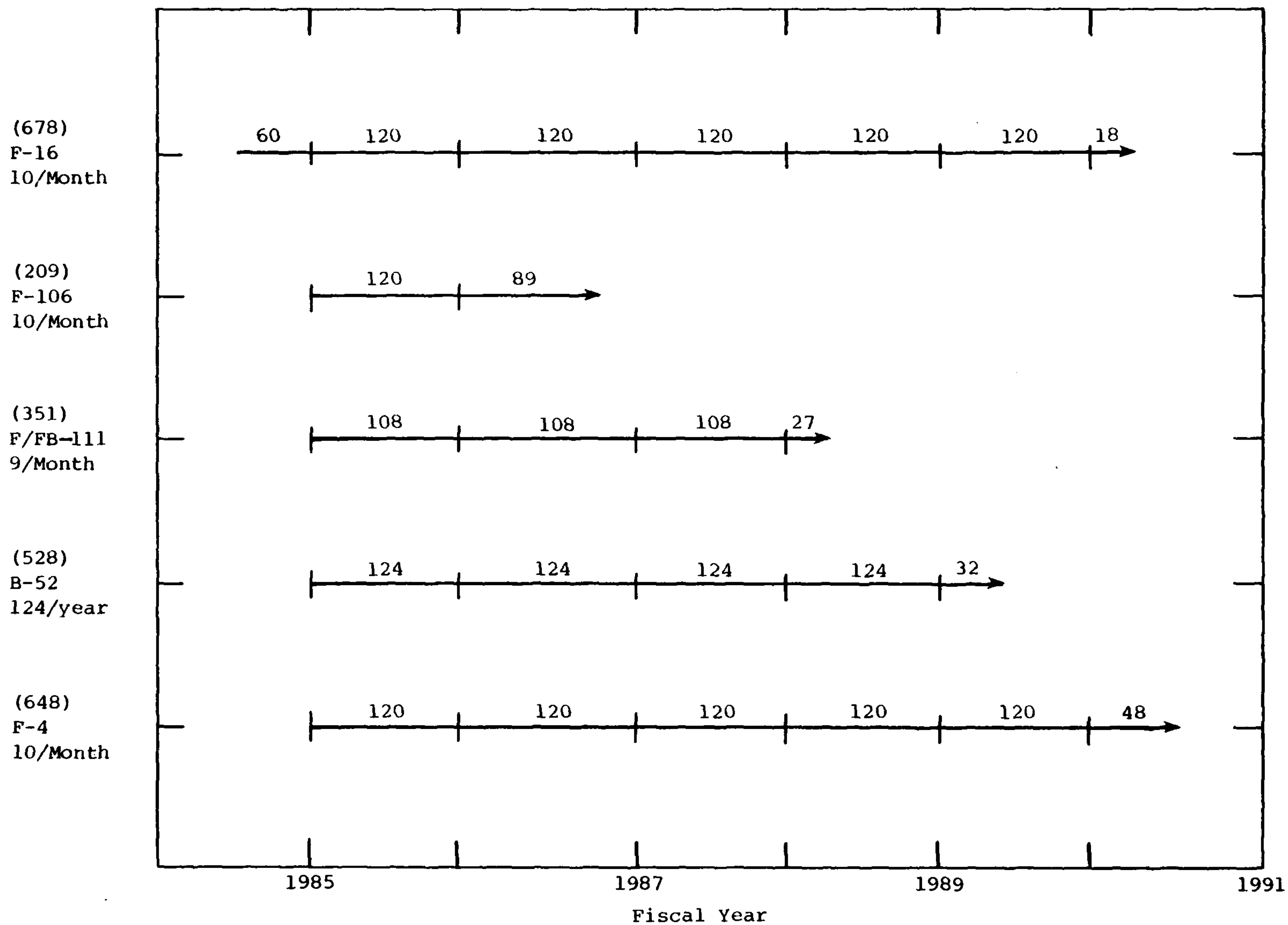

Figure 4-2. LENGTH OF MODIFICATION AND INSTALLATION SCHEDULE

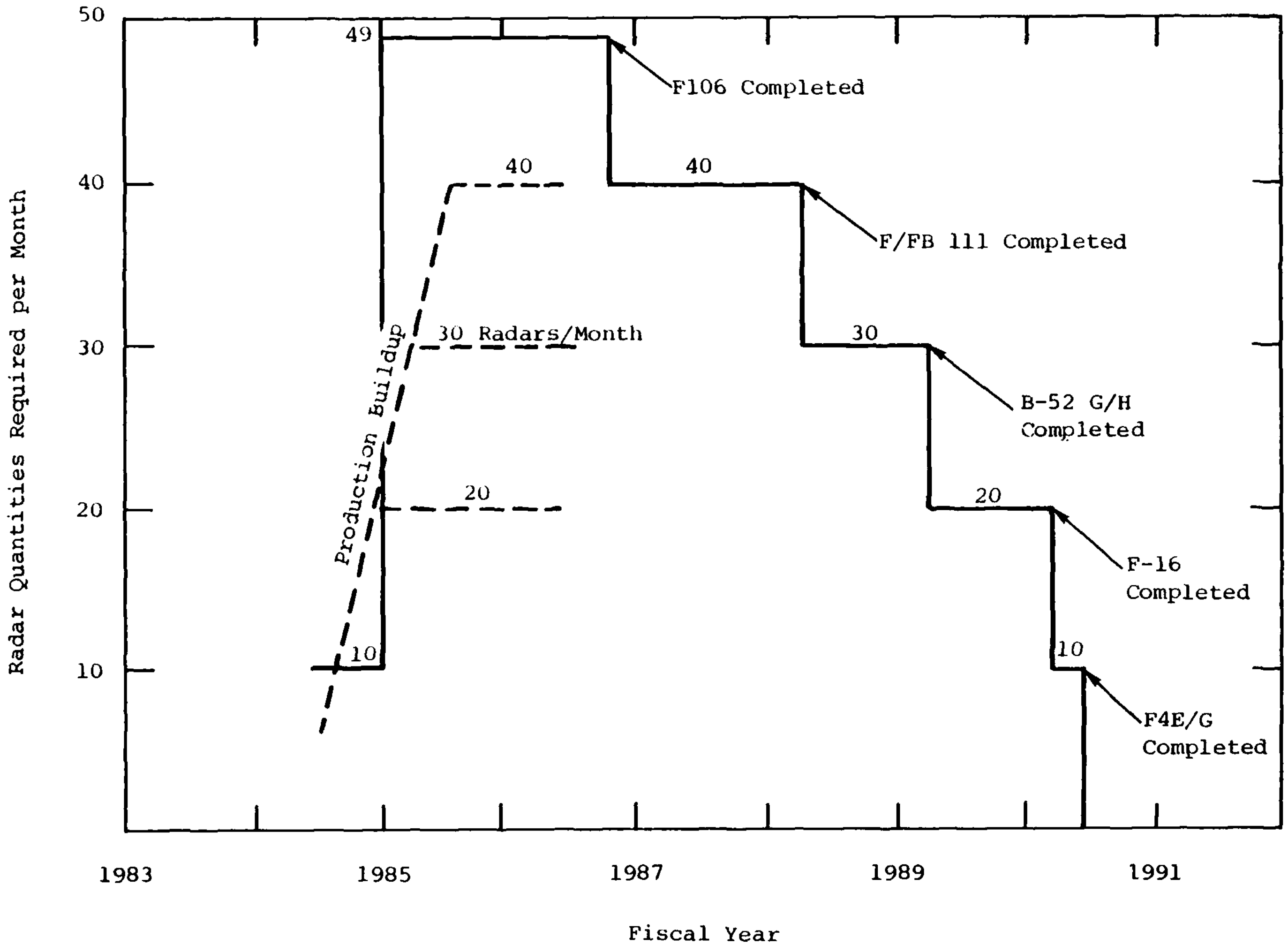

Figure 4-3. AIRCRAFT DEMAND FOR CMMRs (DOES NOT INCLUDE SPARES)

Table 4-3. RADAR DEVELOPMENT COSTS* (FISCAL 1979 DOLLARS IN MILLIONS)						
Aircraft	Software		Hardware		Total	
	Unique	CMMR	Unique	CMMR	Unique	CMMR
F-16	11.4	11.4	53.0	53.0	64.4	64.4
F-106	8.2	2.0	57.0	12.0	65.2	14.0
F-4E	11.4	4.0	52.5	7.5	63.9	11.5
F-111	19.0	11.6	68.0	23.0	87.0	34.6
B-52	11.4	4.0	60.0	15.0	71.4	19.0
Total	61.4	33.0	290.5	110.5	351.9	143.5
Potential CMMR Savings of $208.4M						

*Assumes F-16 Develops Core Hardware and Software; Source Reference: ASD/EN

replacement spares, support equipment, depot and field maintenance, special inspections, supply and support management, personnel training, packing and shipping, and data. Within the scope of this effort, we could not determine the savings that might accrue from the development and use of common support equipment. A separate study focusing on the Level I equipment is recommended for future efforts. For this analysis, Level I support equipment costs of $1.7 million (cost of APG-65 Level I) per support base were assumed. The number of bases (thus Level I quantities) indicated in Table 4-4 is implicit in this assumption. In some cases the same base would use more than one Level I equipment, since it has more than one candidate aircraft, an assumption that may be subject to debate.

AFLC has taken exception to some of the ASD Study cost data. For the sake of traceability to the ASD analysis, we have maintained the original ASD inputs; however, for perspective we have summarized the highlights of an ASD/AERL letter dated 12 October 1979:

- F-4: Add $8-10 million for Class I and II trainer modifications.
- F-106: Add $2.7 million for trainers ($37 million Ogden ALC update required).
- F/FB-111: Add $10 million for trainers and simulators.

Table 4-4. CONSOLIDATED ASD AND ARINC RESEARCH COST DATA (FISCAL 1979 DOLLARS)

Data	F-106	F-111	FB-111	F-4E	B-52G*	B-52H*	F-16
ASD Data							
Assumed Number of Aircraft	228	368	69	685	334	194	738
Basic Cost of Radar (Thousands of Dollars)	560.0	616.0	616.0	495.0	445.0	445.0	400.0
Fleet Recurring Costs for I&I, Unique Equipment, etc. (Millions of Dollars)	81.5	119.5**		546.0	147.0**		--
Total Recurring Costs, per Radar (Thousands of Dollars)	917.5	889.5**		574.7	597.4**		400.0
Hardware and Software Development Cost (Millions of Dollars)	14.0	34.6**		11.5	19.0**		64.4
Annual LSC/Existing Radar (Fleet) (Millions of Dollars)	14.2	21.1	5.4	20.4	14.3	10.4	--
Annual LSC/CMMR (Fleet) (Millions of Dollars)	6.7	8.1	2.3	12.8	8.3	4.8	--
Level I Support Equipment Costs (Millions of Dollars)	1.7	1.7	1.7	1.7	1.7	1.7	Modify AIS
ARINC Research Data							
Assumed Number of Aircraft	209	293	58	648	340	188	678
Recurring Cost (per Aircraft) (Thousands of Dollars)	917.5	876.9	956.6	574.7	597.4	597.4	550.0
Nonrecurring Costs (Development) (Millions of Dollars)	14.0	29.1	5.5	11.5	12.1	6.9	64.4
Annual LSC/Existing (Fleet) Radar (Millions of Dollars)	13.0	16.8	4.6	19.3	14.1	10.1	--
Annual LSC/CMMR (Fleet) (Millions of Dollars)	6.1	6.4	1.9	11.9	8.2	4.6	16.8
Total Level I Support Equipment Costs (Millions of Dollars) (Number of Bases)	22.1 (13)	15.3 (9)	6.8 (4)	27.2 (16)	17.0 (10)	8.5 (5)	Modify AIS

*B-52G/H require two radars per aircraft.
**F/FB-111 and B-52G/H were not handled separately in the ASD Study.

- B-52: Add the following:
  - $20 million (in 1972 dollars) for front and rear radomes.
  - $18 million for flight simulators and trainers, comprising $5 million for software, $10 million for hardware design, fabrication, engineering and support, and $3 million for installation.
  - $3 million for maintenance training.
  - $108 million (in 1979 dollars) for installation, comprising new radome installation, rewiring, and rework of pilot's, copilot's, and navigator's controls and displays, including a new data bus. This projection is based on an estimated installation time of 15,000 hours per aircraft for 270 aircraft.
  - An estimated $13 million (in 1972 dollars) for extensive electromagnetic compatibility and nuclear compatibility testing, both ground and airborne.
- An estimated $50 million to $75 million for depot costs.
- The AFLC analysis performed for RUMM Form 48 submittal indicates that F-106 fleet radar LSCs should be $25 million.

The effect of these exceptions will be discussed in the sections following our analyses.

4.4 TRADE-OFF ANALYSES ASSUMPTIONS

In order to perform the trade-off and risk analyses described below, certain assumptions based on the commonality and life-cycle costing information previously developed by ASD had to be made regarding the number of radars (and of aircraft) that might be required. It is important to understand that if a complete CMMR hardware and software design specification were available today, or if the CMMR were in production, the acquisition strategies would be different than those developed here. Additional development and flight testing must be accomplished in order to achieve the objective of a truly common radar for at least five different candidate aircraft. General issues are the determination of the exact capabilities and reliabilities of the state-of-the-art radars today and a decision regarding how much more performance (if any) designers should attempt to include in CMMR production hardware and software between now and 1985.

Since some CMMR advanced and engineering development still is required to meet all known applications, these assumptions have been made for the analyses to follow:

- The required RDT&E and production funds are the same as those identified by ASD, as adjusted for force structure changes, inflation, and recent F-16 subcontractor revisions.
- A sole-source procurement for the CMMR at this time is not feasible because the potential market is too large.

- Economic paybacks as well as operational needs (including IOC) must be considered.
- The F-16 has the highest priority of the five candidate aircraft analyzed and will be used initially as the test bed for any CMMR program.
- The CMMR will have an MTBF of at least 50 hours.

Using these assumptions and the previous market analyses as a baseline, we changed the market size, radar reliability, logistics support costs, schedule, and acquisition strategies in order to develop a clearer insight into the sensitivities of the numerous factors involved.

4.5 COST PAYBACK FOR EACH CANDIDATE AIRCRAFT

A cost payback chart (Figure 4-4) shows the cumulative expenditures applicable to the new and old radar systems for the FB-111 aircraft.

In the no-CMMR option (lower three curves in the figure), present logistic support costs as developed in the previous ASD study are adjusted to new force structures. They are escalated by 8, 10, and 15 percent per year to determine the total cost if a CMMR is not procured or if R&M improvements to the existing equipment are not made. These escalations represent an 8 percent annual inflation rate, and a 2 percent and 7 percent growth in logistics support costs for reasons other than inflation. Such additional growth might result from increases in failure rate as equipment ages, an abnormal increase in cost of replacement parts due to obsolescence, or similar causes. Curves are plotted for the cumulative cost of the old unmodified radars to the end of fiscal 1991. This approach does not take into consideration the possibility of an existing radar becoming unsupportable because of the manufacturer's lack of interest in producing necessary spares, and thus requiring a unique fabrication contract.

In the CMMR option for the candidate aircraft (other than the F-16) cumulative costs for three periods were developed. The first period represents the time between the present and the first year of installation (fiscal 1985). During this time, the costs are identical to those of the no-CMMR option. The next period represents the investment phase, during which CMMRs are being produced and installed in aircraft at the rates shown in Figure 4-2. Both old and new radars must be maintained during this time; the mixture of old and new changes from all old at the beginning to all new at the end of the investment phase. Logistics support costs for the new radars have been inflated at the 8 percent annual rate, but old radars carry the same three rates mentioned under the no-CMMR option: 8 percent, 10 percent, and 15 percent. No attempt was made to reduce present LSCs as a result of additional (replaced) equipment being available for spares. Investment curves were developed from the costs shown in Table 4-4 and are adjusted for different quantities of aircraft (fiscal 1984 for the F-106, fiscal 1987 for others). Costs included in this phase are ASD estimates of costs for CMMR hardware and software development, acquisition, integration and installation, and unique aircraft (such as a new

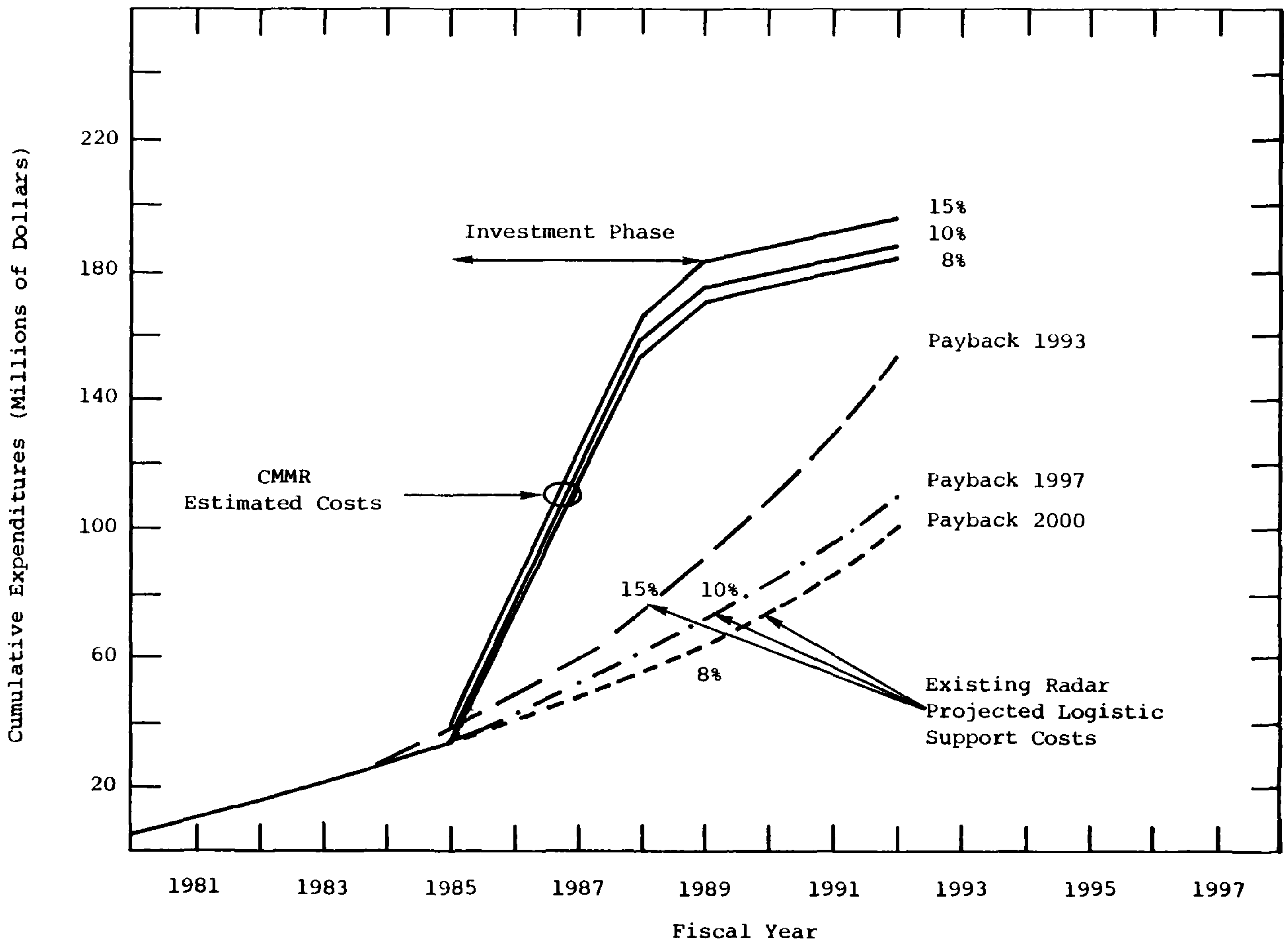

Figure 4-4. CUMULATIVE RADAR EXPENDITURES - FB-111 CMMR VERSUS APQ-114/APQ-134

Environmental Control System [ECS] or new radome). The costs, inflated 8 percent, were calculated on a "per-aircraft" basis -- that is, the non-recurring radar costs were amortized over the aircraft quantity to achieve an average cost for each aircraft.

This procedure produces anomalies in the total expenditure curve. First, because development, acquisition, and installation costs are lumped together and begin at installation, they occur in a shorter time span than normal; the development phase is not uniformly first and distinct. Hence, the curve shows total cumulative expenditures rising more steeply than would actually occur. Second, spending the development money later gives inflation a greater effect. This effect is not significant when amortized in total life-cycle cost. In fact, this results in a conservative estimate of paybacks instead of inflating the development costs over the five-year period before acquisition occurs. After the investment phase shown, the annual expenditures are only for logistic support of new radars.

The date of payback is very sensitive to assumptions of CMMR costs, the start and length of the investment phase, and assumed growth in old logistic support costs. The non-linearity of the overall CMMR curve is produced primarily by the minimal growth in escalated logistic support costs and large expenditures during the investment phase.

The payback dates for each of the candidates (except the F-16) is shown in Table 4-5. Figure 4-5 shows the costs of procuring a CMMR for 678 F-16 production aircraft. Because it is assumed that the radar will be installed "in-line," present LSCs were not used and no payback date determined.

Table 4-5. PAYBACK DATE FOR REPLACEMENT RADARS*

Aircraft	Rate of Logistics Cost Increase		
	8 Percent	10 Percent	15 Percent
F-106	2002	1998	1994
F-111	2001	1998	1994
FB-111	2000	1997	1993
F-4E	2009	2002	1996
B-52G	2004	1999	1994
B-52H	2001	1997	1993

*Payback for the F-16 was not calculated because it is presumed CMMRs are to be installed in production aircraft.

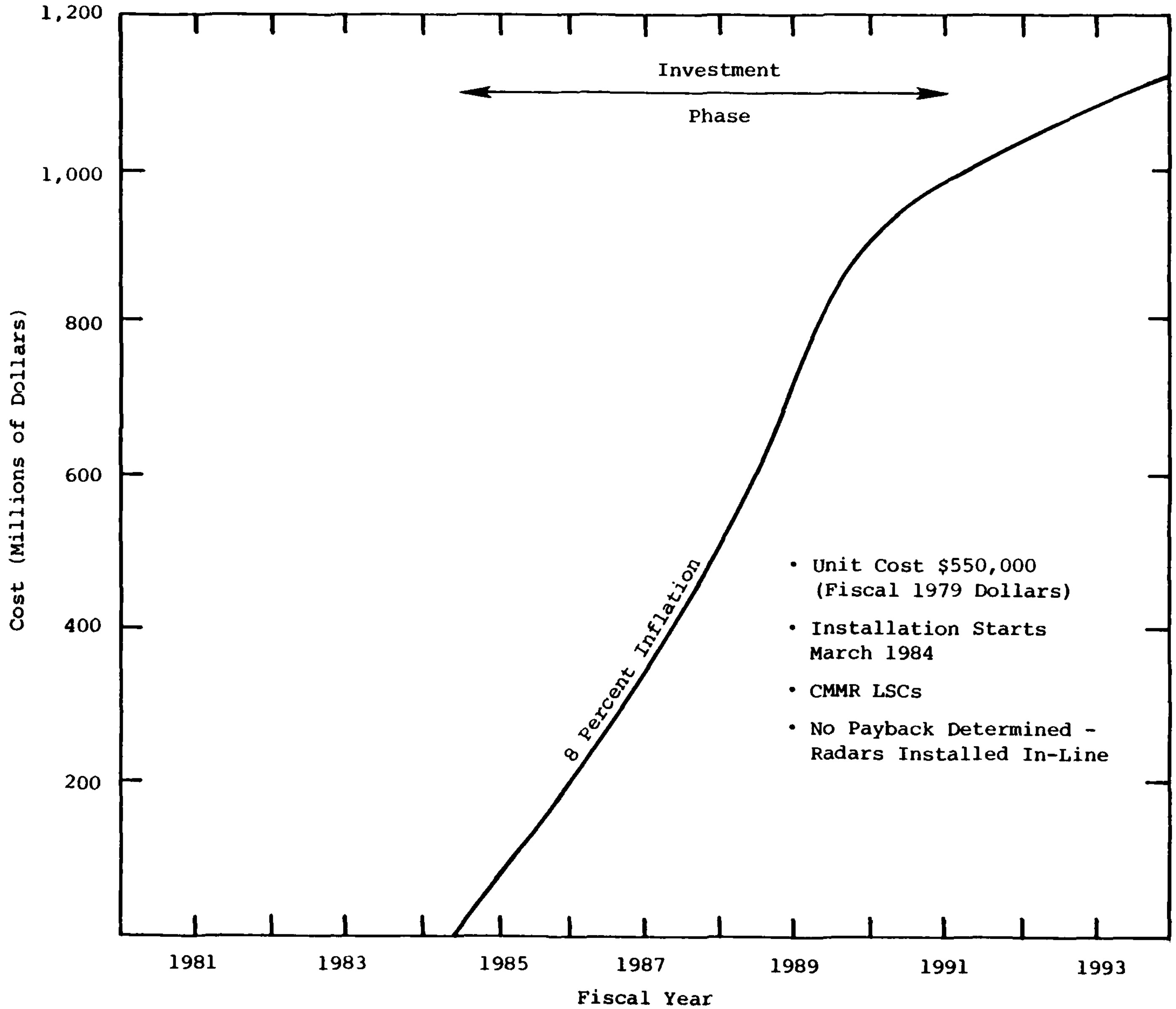

Figure 4-5. CUMULATIVE CMMR EXPENDITURES, F-16

4.5.1 Effect Due to Change in Present Radar Reliability

The F-4E payback occurs much later than the payback for the rest of the candidates because of the length of its investment phase and its current "reasonable" 6.8 hour reliability. We explored the effect of much higher F4E logistics support costs that would result from degradation in reliability. A degradation in reliability for the F-4E to 4 hours by 1981 is considered plausible. This number was extrapolated from a trend curve (Figure 4-6) developed by ASD. The result (Figure 4-7) indicates that a payback date is as much as eight years earlier. Approximately the same result would have been achieved using an LSC growth rate of 11 percent instead of 8 percent, as in the previous curves. This result may be applied generally to suggest the sensitivity of the payback date to reliability for any aircraft.

4.5.2 Effect Due to Change in CMMR Logistics Support Costs

The sensitivity of F-4E payback to the costs of CMMR logistic support was also examined (see Figure 4-8). This assumes the basic 8 percent inflation rate for the LSCs. A 50-percent increase in logistic support costs, which might be caused by not achieving the estimated 50-hour MTBF, would delay payback to fiscal 2025 -- a 16-year delay. Figure 4-9, developed by ASD, shows the relationship of MTBF to CMMR logistics support costs in the F106. A similar relationship exists for each candidate aircraft, although the magnitude will vary somewhat. A 50-percent increase in the $6.1 million F-106 annual logistics support costs at the anticipated 50-hour MTBF would be caused by a degradation of the MTBF to about 28 hours.

4.5.3 Effect Due to Change in CMMR Unit Cost

We further examined the sensitivity of payback year to changes in CMMR unit cost in the case of the F-4E. The results of this analysis are shown in Figure 4-10 for the 8 percent inflation case. The expected payback year is not very sensitive to CMMR unit cost. A $200 thousand increase (40 percent) in unit cost from the $495 thousand baseline, for example, would delay payback to fiscal 2012, some 27 years after initial installation begins, yet only three and one-half years later than without the increase.

4.5.4 Effect Due to Change in Installation Rate

The F-4E installation rate is comparable to the rate for the other candidate aircraft, but because of the assumed size of the fleet (648 aircraft), the installation schedule could not be completed until mid 1990. Figure 4-11 depicts the effect of an accelerated installation rate in which the fleet is completely retrofitted by 1989 (40 aircraft per quarter). The assumption was made that the additional radars (plus spares) required would be available. Payback dates would be improved over those using the originally assumed installation rate by approximately one year, indicating a relative insensitivity to installation rate. This insensitivity is due to the much greater effect of acquisition costs during the investment phase.

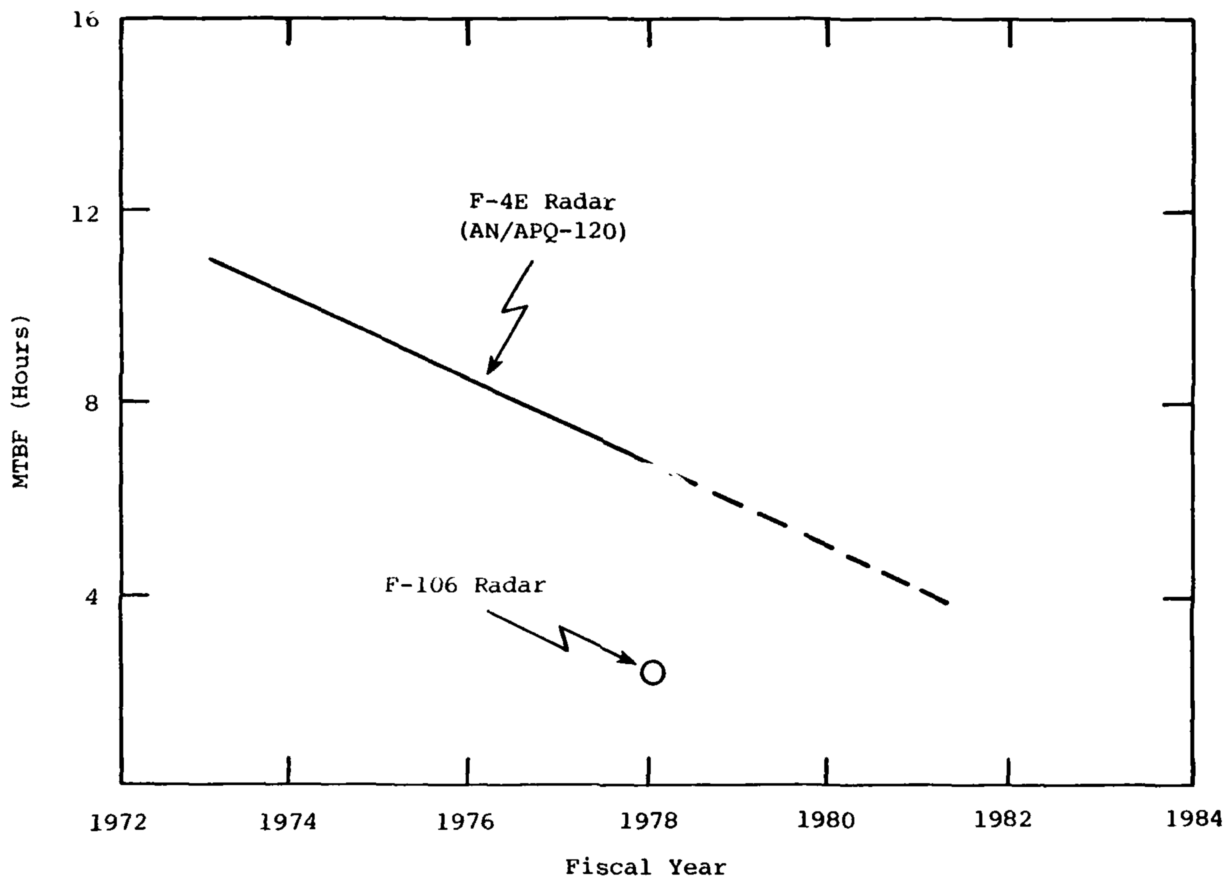

Figure 4-6. F-4E RADAR RELIABILITY TREND

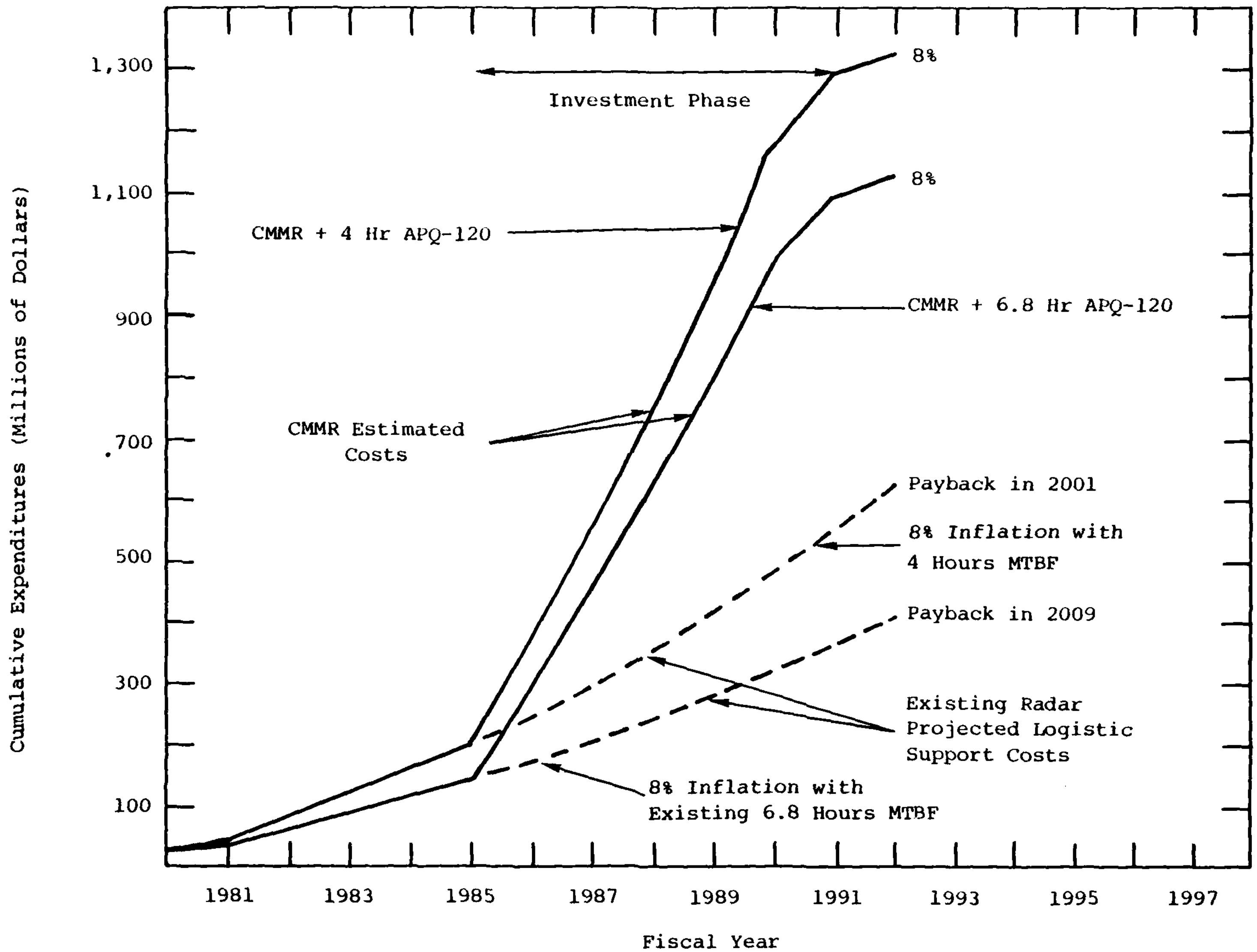

Figure 4-7. CUMULATIVE RADAR EXPENDITURES - F-4E CMMR VERSUS APQ-120 (TWO MTBFs)

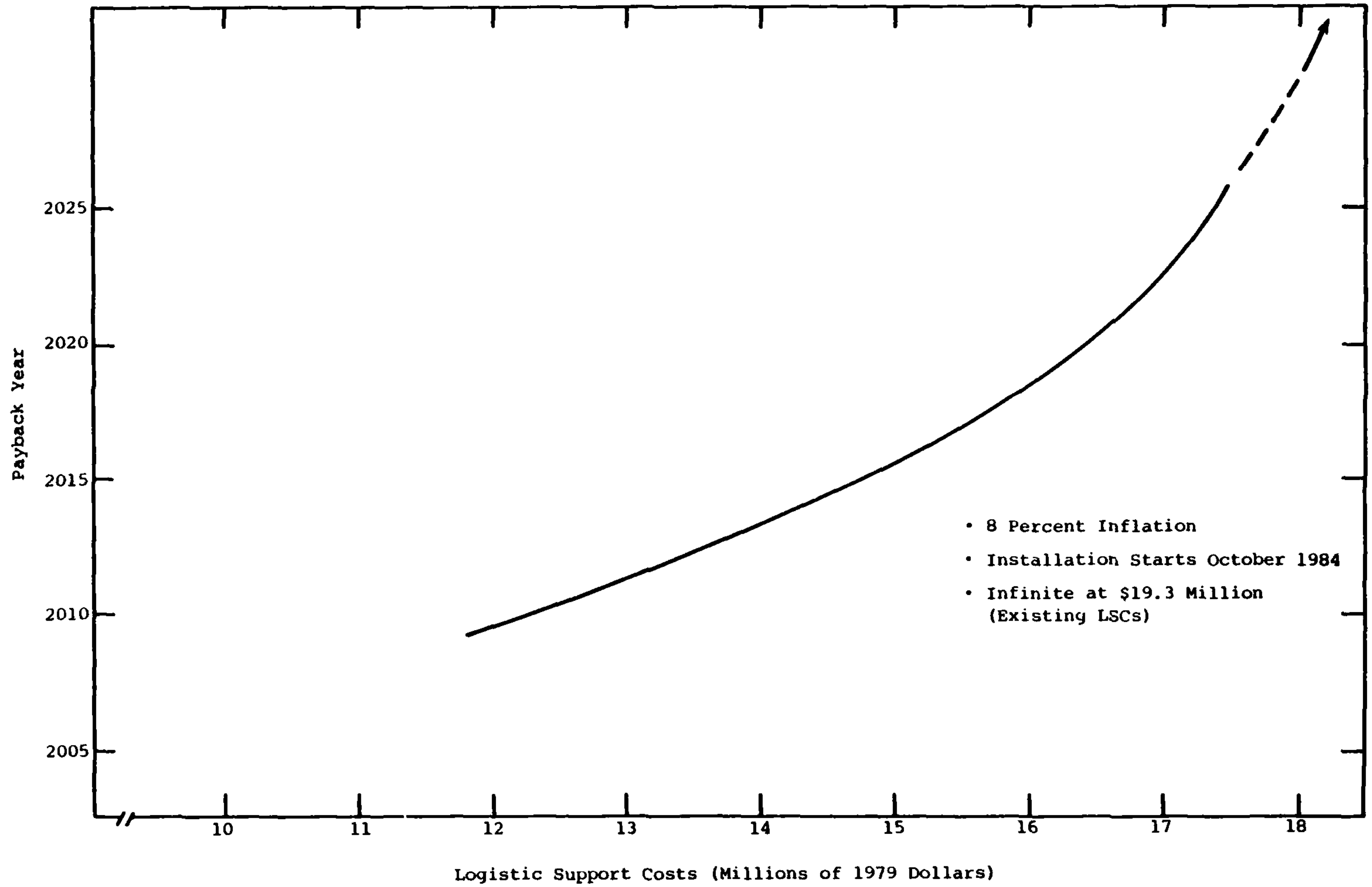

Figure 4-8. F-4E PAYBACK YEAR AS A FUNCTION OF CMMR LOGISTIC SUPPORT COST

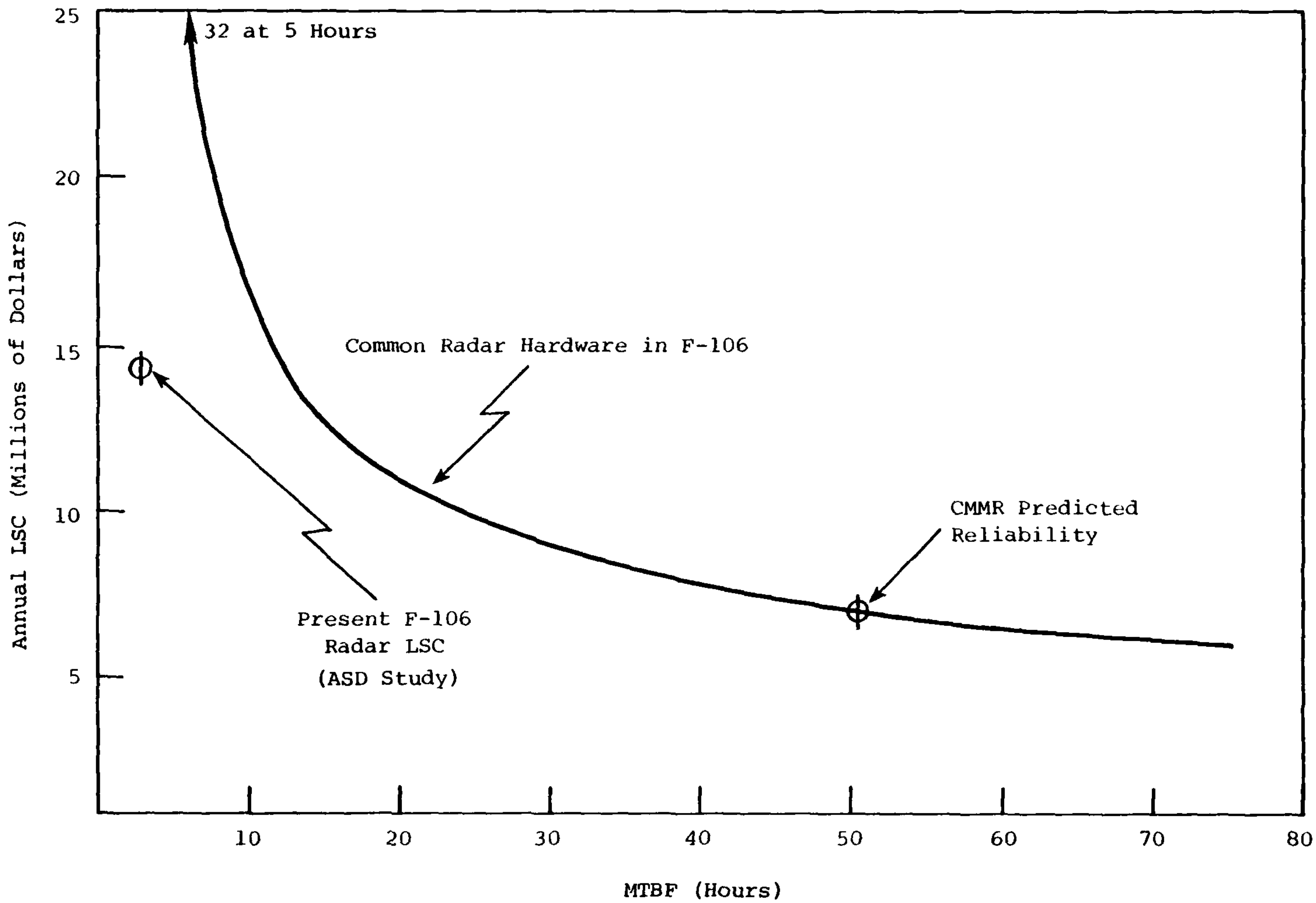

Figure 4-9. PROJECTION OF F-106 CMMR ANNUAL RADAR LOGISTICS SUPPORT COSTS IN RELATION TO MTBF (FISCAL 1979 DOLLARS)

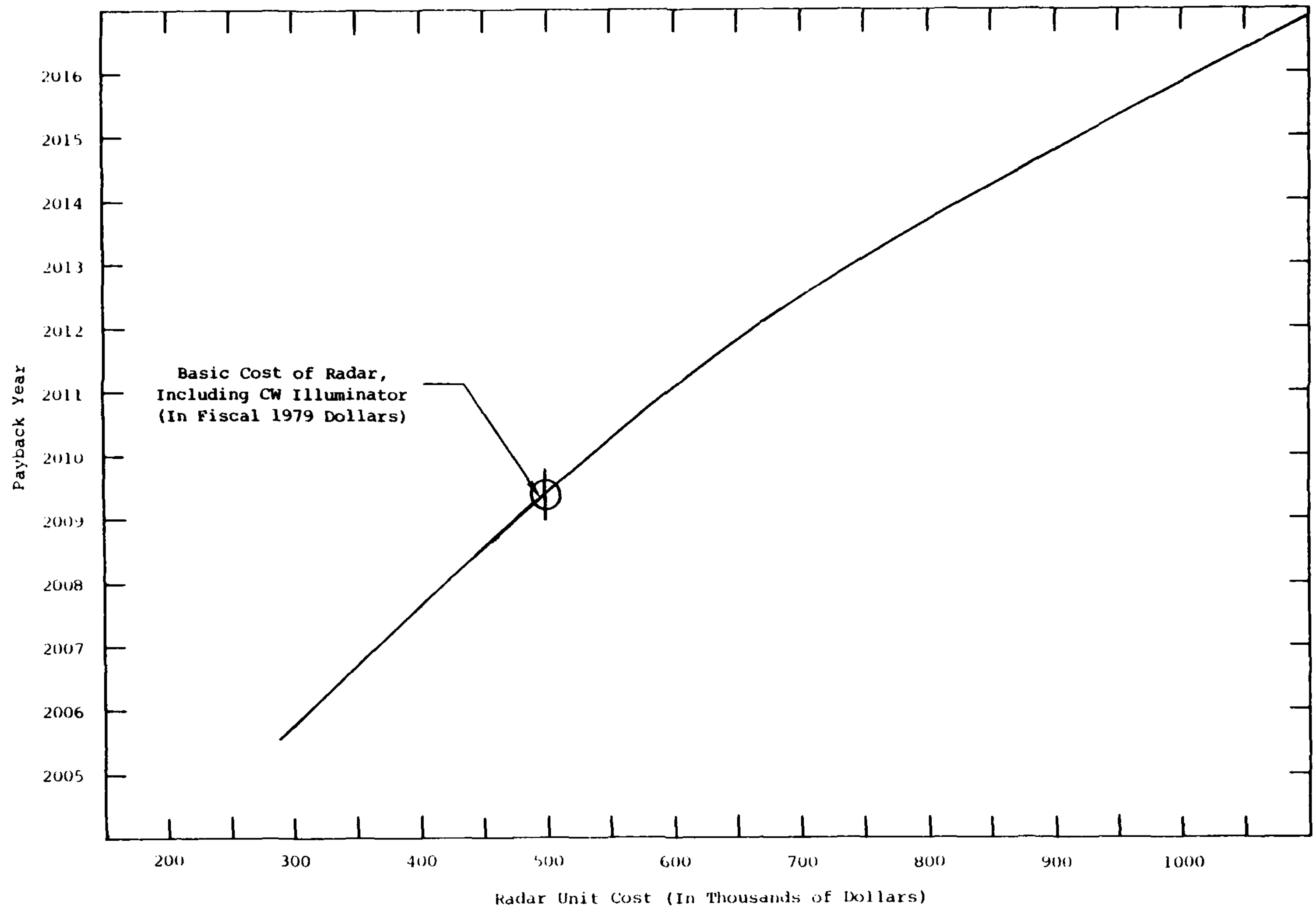

Figure 4-10. F-4E PAYBACK YEAR AS FUNCTION OF CMMR UNIT COST (INSTALLATIONS START IN 1985)

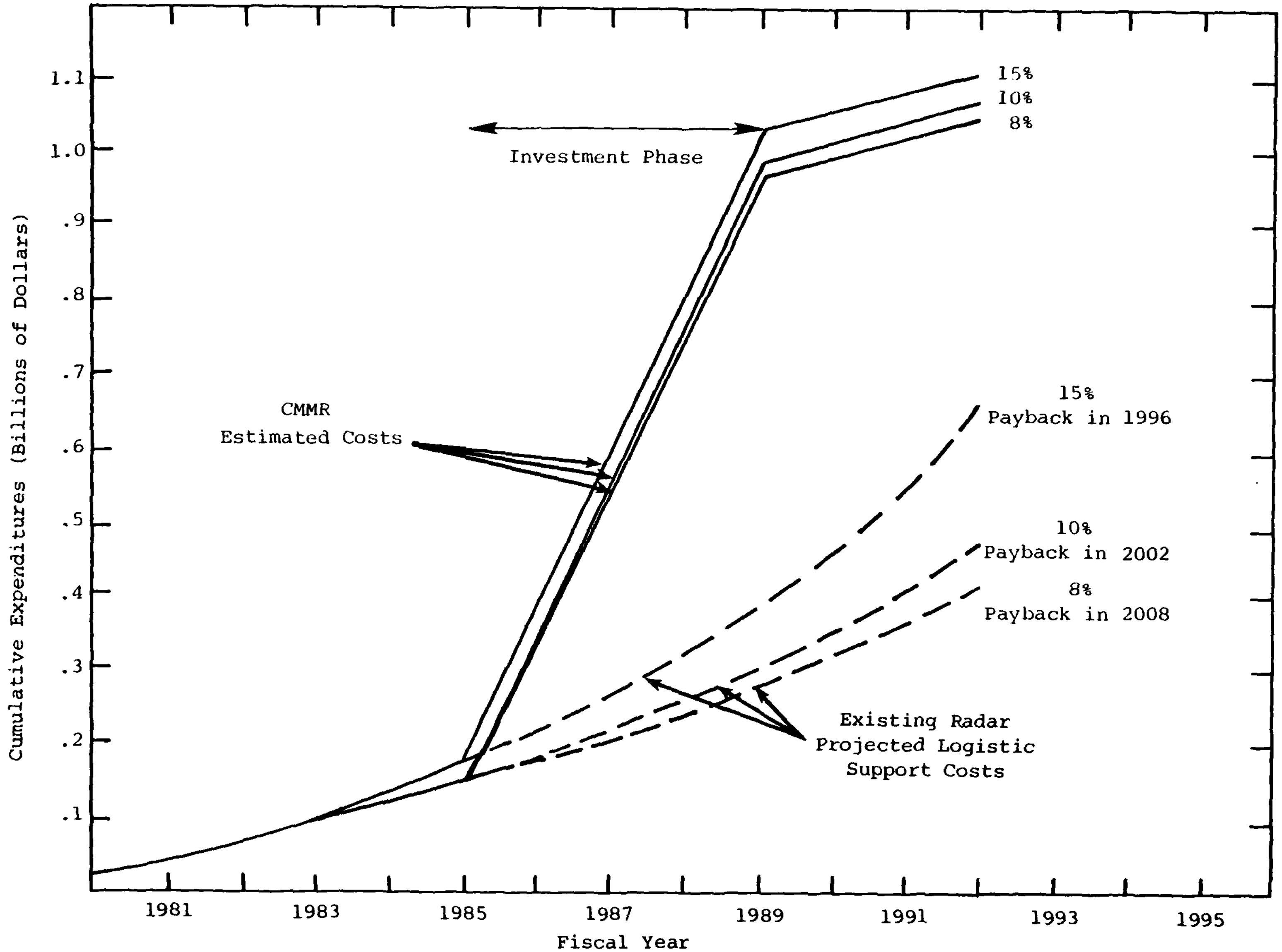

Figure 4-11. CUMULATIVE RADAR EXPENDITURES, F-4E CMMR VERSUS APQ-120; ACCELERATED INSTALLATION

4.5.5 Effect Due to a Combination of Factors

As a composite "best-case" scenario for the F-4E, we assumed an accelerated installation rate, a degradation of the MTBF of the currently installed radars to 4 hours by fiscal 1981, and a 15 percent annual increase in logistics support costs. Figure 4-12 shows a payback under those conditions occurring in 1993; that is delayed one year to 1994 if the installation rate is the earlier-assumed 10 per month. This scenario is not unreasonable, especially in the light of the current rapid growth in technology that produces obsolescence far more quickly than in the past. The F-4E could therefore be as attractive a candidate as the other proposed aircraft, especially if worsening reliability and the need for additional operational capabilities (requiring a new radar) become significant factors.

4.5.6 Effect Due to Change in CMMR Installation Schedule

The start of the investment period for the individual candidate aircraft, except the F-16, was moved from fiscal 1985 to fiscal 1987. The assumption was made that the F-16 would be on time (March 1984) and the other aircraft would still have common radars. Installation would be delayed until October 1986. There are other variations in this schedule approach. One might be to install some of the radars (in the F-106 and B-52) on schedule, but delay installation in the other aircraft (F-4 and F/FB-111) until later (such as fiscal 1987 or 1989) because of budget constraints. Table 4-6 shows the payback dates that would result from those changes. This analysis indicates the desirability of developing a CMMR as soon as possible, although payback is not very sensitive to the CMMR schedule.

4.6 SEQUENTIAL VERSUS PARALLEL DEVELOPMENT AND ACQUISITION

As we indicated in our report on the market analysis in Section 4.2, assuming that no significant cost increases (as for tooling) are allowed, a single manufacturer cannot develop and produce enough radars in the critical four-year period (fiscal 1985 to 1989) to meet the projected demands of simultaneous installation in five candidate aircraft.

The capability of a single manufacturer to produce, on schedule, as many as 40 high technology radars per month is doubtful when current rates are only 10 to 20 per month. It is highly likely that radar manufacturers will already be producing equipment for other programs. In addition, if installations are attempted in all aircraft simultaneously during fiscal 1985 -- where the hypothetical demand is for more than 40 radars each month -- some additional monthly quantity (perhaps as high as 8) would be necessary for sparing purposes.

If the assumed demand during the period reviewed is valid, a second manufacturer must be brought on board. If the program were to involve a single manufacturer (perhaps desirable to reduce engineering risk and support costs), alternatives would be to lower the demand by limiting the number of specific monthly individual aircraft installations or the number

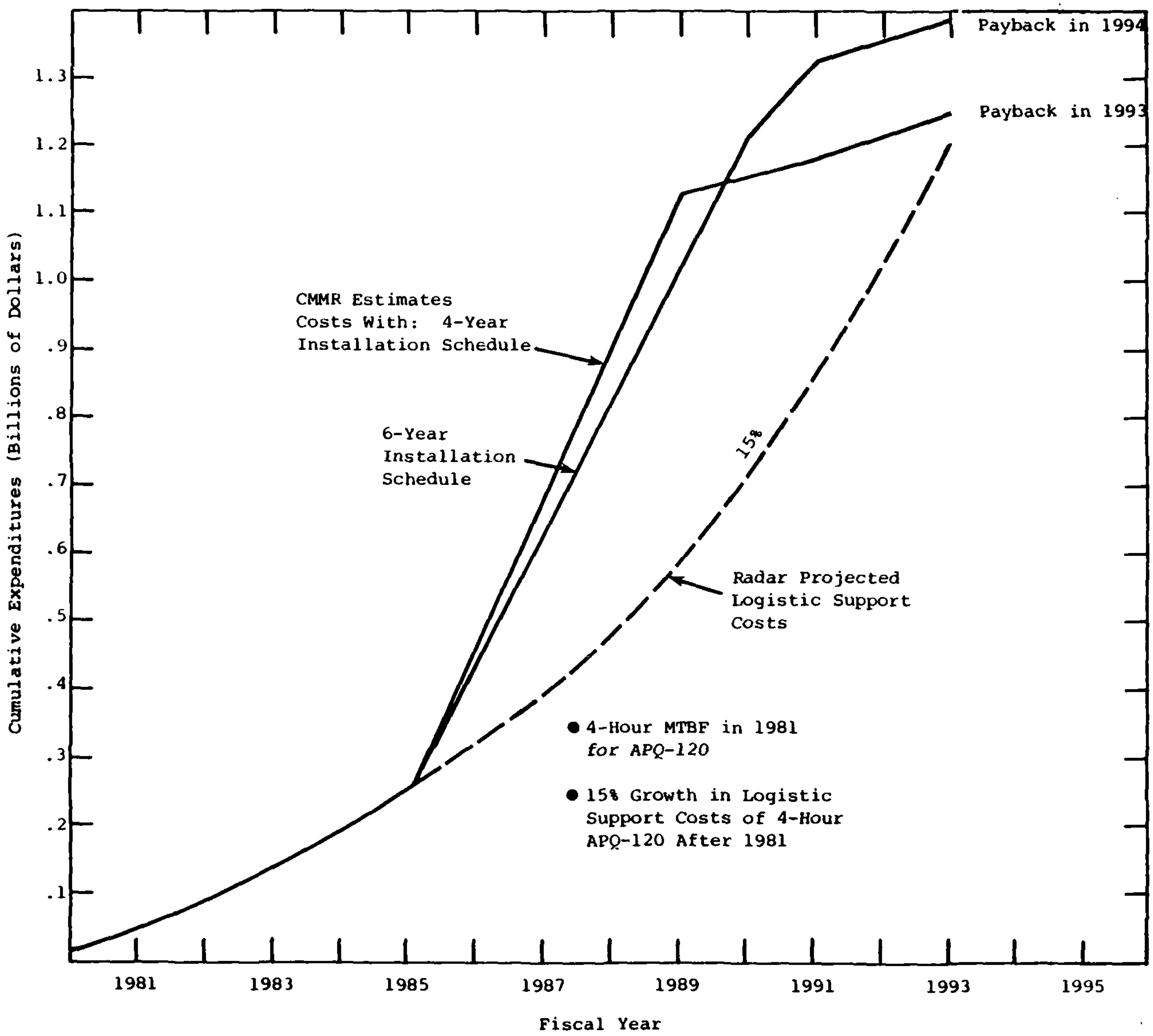

Figure 4-12. CUMULATIVE RADAR EXPENDITURES, F-4E: CMMR VERSUS APQ-120 (Two Different Installation Rates)

Table 4-6. PAYBACK DATES FOR REPLACEMENT RADARS* -- 1987 START			
Aircraft	Assumed Inflation Rate		
	8 Percent Growth	10 Percent Growth	15 Percent Growth
F-106	2003	2000	1995
F-111	2003	2000	1995
FB-111	2002	1999	1994
F-4E	2011	2004	1997
B-52G	2006	2001	1996
B-52H	2002	1998	1994

*F-16 payback was not calculated because it was assumed that CMMR would be installed in production aircraft.

of candidate aircraft involved, or by staggering installations, thus extending the schedule with the result of higher costs, reduced operational capability, and later payback.

4.7 COST SAVINGS THROUGH COMMON DEVELOPMENT AND QUANTITY BUYING

If the radar demand drops to a point where it is possible for a single manufacturer to meet the market for all systems, the parallel technology and aircraft unique study and development efforts discussed earlier should continue ahead of any production in order to take maximum advantage of common hardware and software for later modification programs. For this analysis, the unique and common aircraft hardware and software development costs shown in Table 4-3 and the additional costs shown in Table 4-4 were inflated at an 8 percent rate and spread out over the development period (assumed to have already begun with current technology efforts) and the installation period (assumed to begin in fiscal 1984 with the F-16).

Additional funding in fiscal 1980 would be required for any accelerated CMMR program. The F-16 program allocated $2 million in fiscal 1979 for the PSP and transmitter development work mentioned in Chapters Two and Three to improve the existing Westinghouse radar. We assume that $2 million is included in the ASD development funding allocation for the F-16 ($64.4 million shown in Table 4-3). We also assume that any additional money required for the F-16 CMMR test-bed aircraft for the proposed dual source flyoff would be provided by SPO.

Using our estimate of fiscal 1979 average unit cost for the F-16 Radar ($550 thousand) from Table 4-4, we calculated an initial unit cost on the basis of an assumed 90 percent learning curve. A first unit cost ($1.258 million) for the CMMR was computed assuming, as in the ASD Study, that the costs for the individual radars are about the same even though they have some unique components. A 90 percent learning curve (Figure 4-13) was developed and entered for each individual aircraft quantity required, regardless of the acquisition approach used. The cost of each radar was inflated to then-year dollars, using an 8 percent inflation rate. In a competitive environment other factors, such as buy-in, could influence this price. Illuminator and other aircraft costs have not been included, since these are independent of acquisition strategy. The budget estimates developed are comparable to those used in a recent ASD briefing. They do not consider the AFLC inputs identified previously. Our assessment is that increases due to the AFLC costs equally affect each of the approaches used in this analysis and do not alter the results significantly.

4.7.1 Program Comparisons

Three alternatives were investigated:

- The hypothetical CMMR program as defined in our analysis. A four-year development cycle has been postulated in which radars would be installed in F-16s beginning March 1, 1984, and in the other types of aircraft starting October 1, 1984.
- A "split-buy" program (two awards for a single procurement cycle). In this case, approximately half the radars would be developed and procured from one manufacturer and the remainder from another in parallel. This case would not offer the total benefit to be derived from a common radar program. The two manufacturers are assumed to have hardware and software designs that are different, requiring additional development money to meet all the aircraft applications assigned (although other investment costs were assumed to be the same). For the first award, the lead aircraft again would be the F-16, and F-4E radars also would be procured from this manufacturer. For the second award, the lead aircraft would be the F/FB-111, and the second manufacturer would also develop and produce radars for the B-52 and F-106. The increase in total development costs ($52.4 million) required thus would be attributed to the F/FB-111 and be spread out over the projected four-year development cycle. The schedule would remain the same as in the first alternative.
- An "all unique" separate approach. Separate development and complete separate buys for five different aircraft are highly unlikely. However, it is highly probable that more development money will be required if the Air Force does not procure common hardware and software in the near future rather than pursuing separate designs. For example, an R&D cost of $25 million has already been estimated for the F-106 RUMM. It is also highly likely that although radars with separate and reduced capability for some applications might

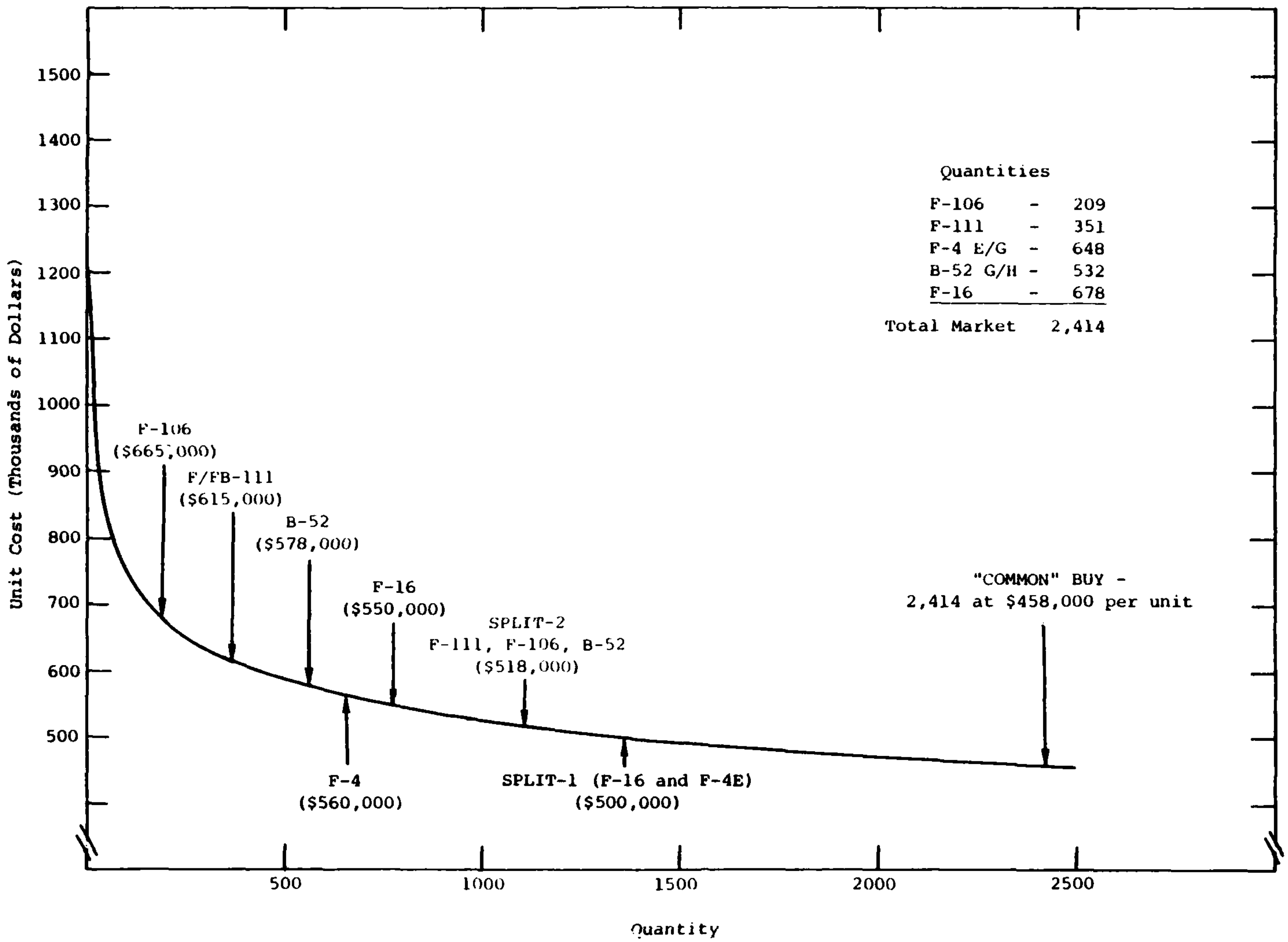

Figure 4-13. POTENTIAL CMMR UNIT COST (FISCAL 1979 DOLLARS) VERSUS QUANTITY -- 90 PERCENT LEARNING CURVE

each cost less during development and acquisition than a single CMMR, the total LCC for the various radars would undoubtedly be more because they would not benefit from the learning curve and common LSC savings.

The following conservative assumptions have been made:

•• Separate-buy development, because of unique design approaches, would cost approximately twice as much ($300 million) as a common buy (CMMR) program.

•• Similarly, total costs for modifying existing aircraft radars would cost as much as buying new radars if an MTBF of 50 is required and major modification is not cost-effective.

•• All of the candidate aircraft would require some improvements to their existing radars if the force structure planning remains valid. Therefore, all candidates will receive new radars.

•• Any improvements through either new radar procurement or modifications to old radars would be prolonged, and the new development cycle would take as long as six years, although the projected installation schedule would remain the same.

On the basis of these assumptions, we calculated the costs of a separate-buy program. We reduced the ASD development costs from $352 million to $300 million and spread them out over six years rather than four, as in the first two alternatives. The F-106 installation schedule was moved forward a year, and the F/FB-111 and B-52 radars were scheduled to be developed at the same time in five years. The F-4E radar development was assumed to take five years and would be the last aircraft radar to be installed. Overall, the schedule is two years longer than in the first two alternatives because of the F-4E delay.

4.7.2 Potential Savings

Figure 4-14 presents the results from the three alternatives investigated. No particular significance should be attached to the crossing of the curves; the separate program would delay the F-4 development by one year and hence delay a large annual increase. Savings over any separate-buy approach would accrue for both the CMMR and split-buy cases because of shared development costs and production learning-curve rates.

This analysis does not attempt to estimate the different LSC or LCC involved (although they should be much higher in the separate-buy case) and does not include any unique aircraft hardware acquisition costs such as ECS, radomes, individual Level I support equipment, or integration and installation costs, since similar amounts would be required in any case, provided the equipments were similar. It does point out, however, that either of the first two approaches has the potential for very large acquisition-cost savings over buying different radars for each aircraft, even though the first two alternatives should not be compared directly with the last one.

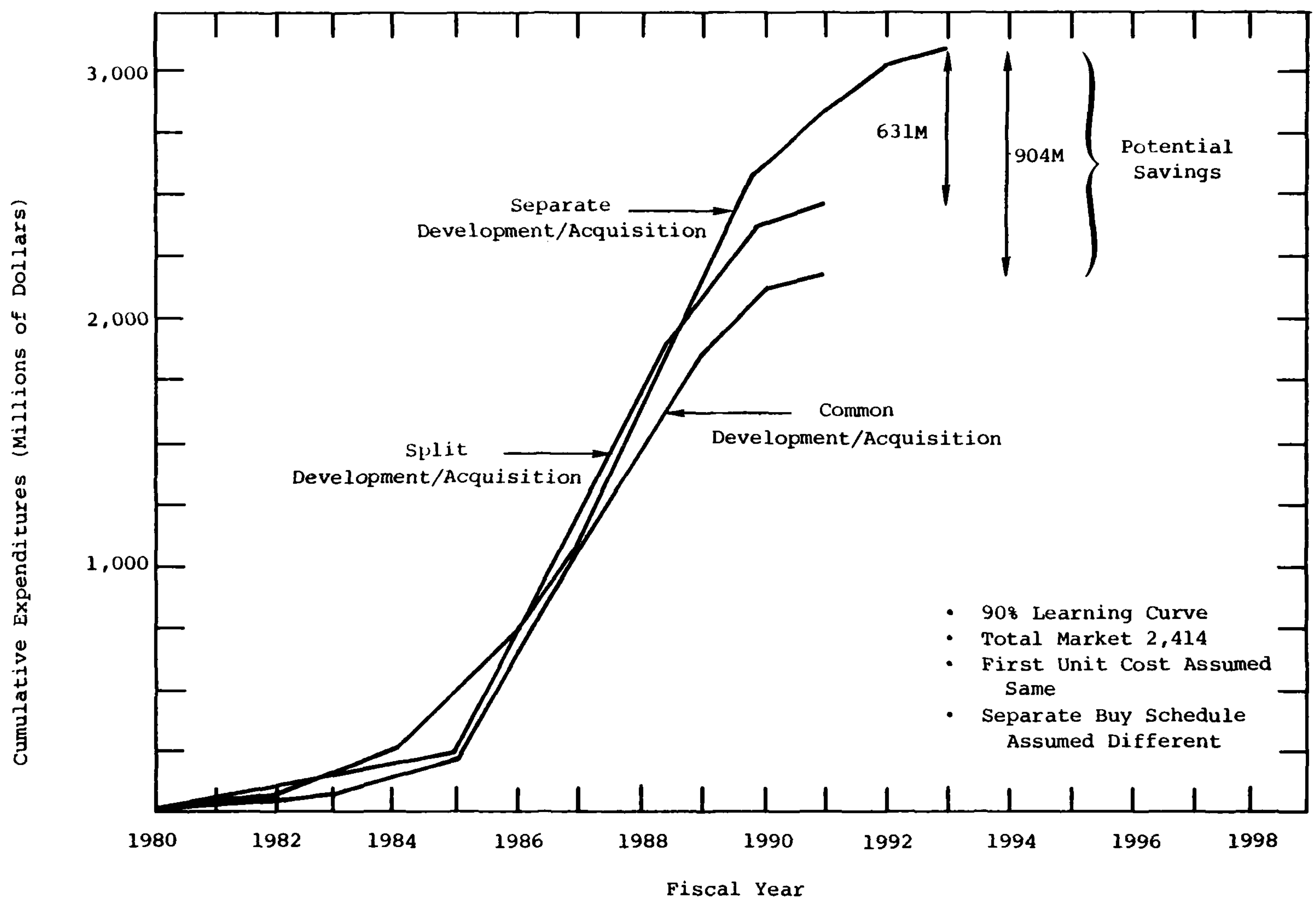

Figure 4-14. COMMON, SPLIT, AND SEPARATE BUY CUMULATIVE ACQUISITION EXPENDITURES

4.8 COST SAVINGS IN A REDUCED MARKET

Another variation of the above analysis is to limit the quantity of common radars procured to approximately half. This could be the result of funding or other considerations. We examined the costs of acquisition under such a reduced market. We assumed that the F-16 would remain a full candidate for CMMR but no F-106, FB-111, or B-52H aircraft would be candidates, and that only the PAVE TACK F-4s and F-111s (approximately 300 and 100 respectively) were candidates, and finally that only one radar was required in the B-52G. This reduced the market size to 1,250. Figure 4-15 shows that even with this scenario, a healthy savings ($494 million then-year dollars) would result from common development and procurement rather than following the separate-buy approach. The two curves cross in fiscal 1985 because the separate program would delay development and acquisition of the F-4, causing the rate of expenditures to be even higher than would be expected from the separate program's higher cost.

Figure 4-16 presents the results of a similar exercise with the exception that the reduced procurements are slipped (other than the F-16) from fiscal 1985 to fiscal 1987. This situation might occur as a result of procurement money restrictions or some similar change. These curves should not be confused with the results of the cost-payback analyses performed earlier in which LSCs were included and timing was important because of escalating LSCs on existing radars. Note that even after such a program slippage, 445 million then-year dollars can be saved by a common development. In other words, the potential acquisition savings available through common radar development and procurement are not particularly schedule-sensitive, assuming no drastic market change, further supporting the results in Section 4.5.6.

4.9 SUMMARY OBSERVATIONS

The separate development costs given in Table 4-3 were originally estimated by postulating radars with identical capabilities. However, if separate buys costing $352 million for development were to occur, would an average of $88 million in P 3600 funds annually for a four-year development cycle be available? Would the same installation schedule apply? Might not some of the five candidate aircraft be modified with some common LRUs from other programs already in production? Because of funding constraints, could some unique aircraft radar capabilities be traded off and a reduced-capability radar be installed on some aircraft instead?

It should also be noted that decisions by Air Force planners on whether and how to split any total CMMR buy between at least two vendors become difficult when more than one aircraft is included in the procurement. Only if the radar system is identical (to piece-part level) for two or more different aircraft installations and a common spares pool is used are the penalties for buy-splitting (such as cost to qualify a second source) the same as for a procurement for a single airframe. Without standardization, additional penalties (such as unique support equipment) are incurred by each procurement. Even though for this study the LSCs were assumed to be the same, they would undoubtedly be different. Depot requirements might also be different.

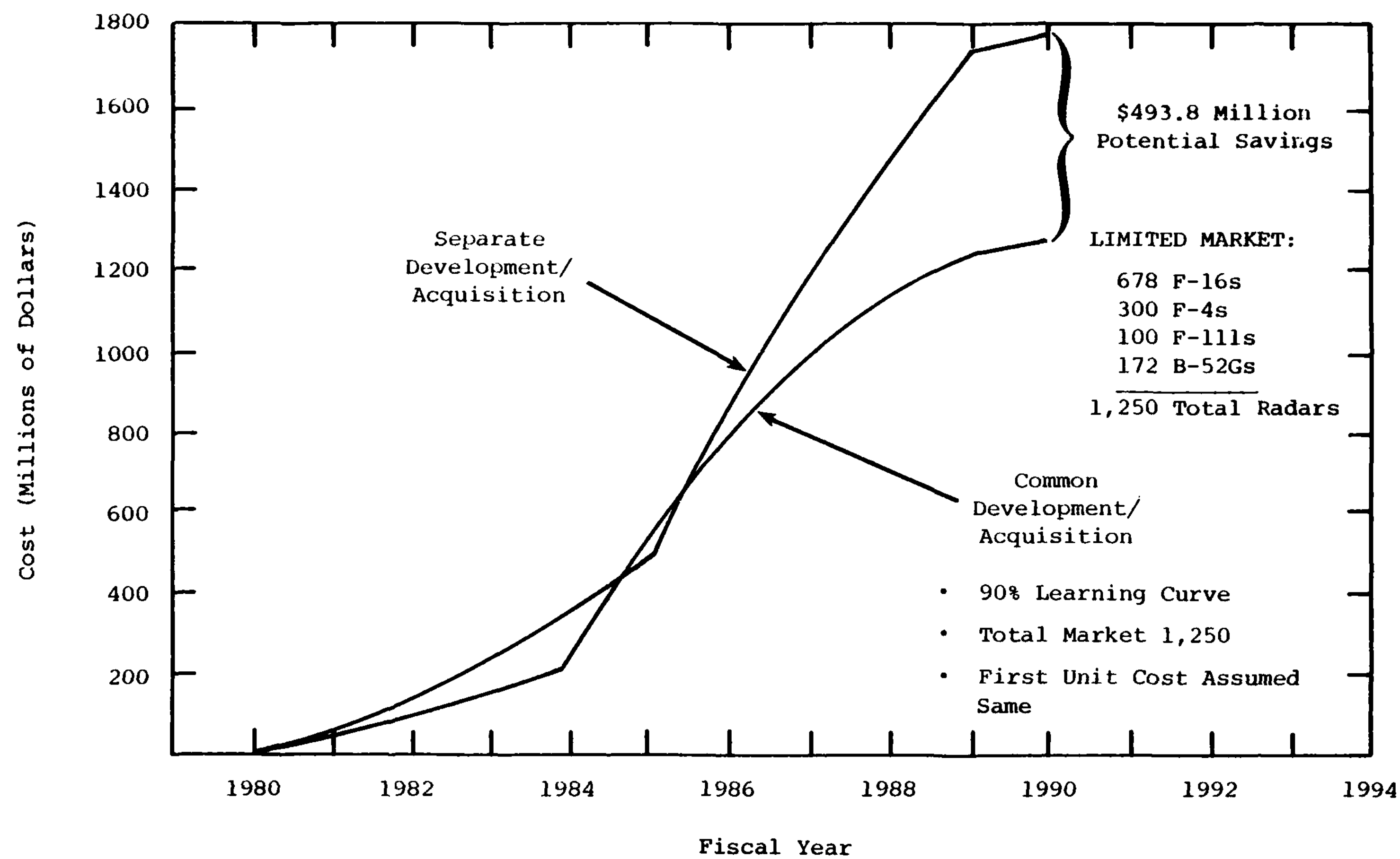

Figure 4-15. ON-TIME LIMITED MARKET COMMON/SEPARATE CUMULATIVE EXPENDITURES (Then-Year Dollars)

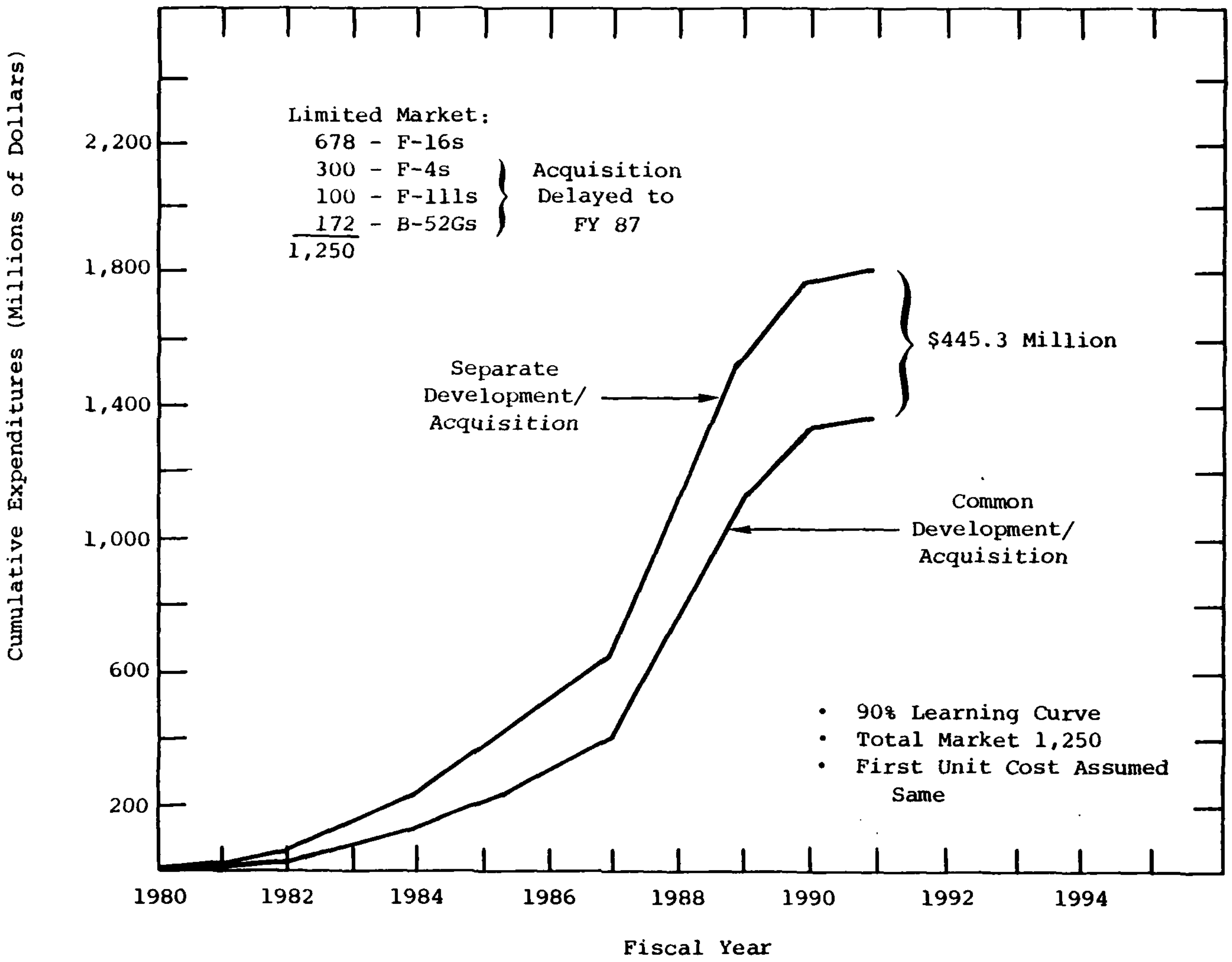

Figure 4-16. CUMULATIVE EXPENDITURES (Then-Year Dollars)

The method for buy-splitting when two or more aircraft are under consideration depends on the number of aircraft and the timing of their respective procurement cycles. For example, if there are two aircraft and two potential CMMR suppliers, there are four possible scenarios:

- Split the buy on one aircraft only and award a single contract to the lowest bidder for the remaining aircraft
- Split the buy on both aircraft
- Split the buy by aircraft
- Award the total buy to the lowest bidder

There are many factors that influence the feasibility and desirability of exercising these options, including the following:

- Differences in anticipated reliability (and warranty effects) for different aircraft
- Economic trade-offs
- Distribution requirements
- Contractual terms (warranties or other guarantees)
- Suppliers' production-rate capabilities
- Operational considerations

These factors, discussed in greater detail in Chapter Six are also important when reviewing standardization approaches, discussed in Chapter Five.

CHAPTER FIVE

STANDARDIZATION APPROACHES

5.1 INTRODUCTION

As a corollary to our acquisition strategy we have examined several standardization approaches. Previous studies* have shown that the technology represented by attack radars is not ideal for system or form, fit, and function (F^3) standardization. The technology is not mature -- new modes and increased performance requirements for airborne attack radars are constantly being developed. The architecture of existing airborne radar systems is not particularly discrete. In fact, over the years the radar has become an integral part of the weapons system. It has interfaces with a large number of different aircraft avionics subsystems that vary among aircraft mission design series (MDS). Radars do have a rather broad avionics applicability, perhaps not to the extent of a "black-box" TACAN or UHF radio, but with the advent of programmable signal processors (PSPs), the same radar hardware can be applied to multiple MDS, increasing its applicability over a wider range of aircraft. This expanded applicability brings the potential for economic advantage. In fact, a common multimode radar for several aircraft can save substantial acquisition costs as shown in the previous chapters of this report.

A standard airborne attack radar only partially satisfies the criteria recognized for standardization candidates. Its lack of a mature technology or discrete architecture suggests that if standardization were imposed upon the present attack radar market some cost or performance penalties would be paid. The savings from large quantity buys and common spares and support equipment could easily be offset by the cost of aircraft ECPs and radar modifications necessary to have a standard radar system and aircraft meld properly. Additionally, certain unique operational requirements would likely not be met, or met only with expensive unique hardware.

5.2 LRU/SRU STANDARDIZATION

Between the "separate radar for separate aircraft" approach and the standard radar system approach, lies an alternative that can yield

**Air Force Avionics Standardization: An Assessment of System/Subsystem Standardization Opportunities*, S. Baily, D. Martinec, A. Savissar, and N. Sullivan, ARINC Publication 1910-13-2-1722, March 1978.

substantial cost savings while compromising only slightly the requirements of each aircraft -- LRU and SRU standardization.

The Line Replaceable Unit/Shop Replaceable Unit (LRU/SRU) approach recognizes that even though the complete radar system might perform entirely different functions from one MDS to another, there are certain discrete and well understood subsystems in every radar. Additionally, the maturity of airborne data processing has brought about the powerful new LRU, the programmable signal processor (PSP). Radar hardware architecture can now be common to all aircraft. A radar's ultimate output can change by means of software to satisfy the unique requirements of a particular aircraft or weapons system in which it resides. Sophisticated radar computer subsystems now employ technology that may be more mature and have relationships with their neighbors (interfaces) better defined than is true of the entire system of which they are a part.

5.2.1 Penalties of Limited Standardization

There are economic and management penalties if any limited standardization approach is pursued. Instead of the cost advantage gained from buying a large quantity of an entire radar system, only a portion of the system (common LRUs and SRUs) enjoy any large quantity-buy advantage. From a management standpoint, the potential advantage of reducing the costs through competition is affected by the need for either an integrating contractor, or for the Air Force to handle the integrating effort itself. Undoubtedly, additional program management and engineering personnel (of the proper skills) would be required.

The economic advantage of system standardization is that the entire radar (in our analysis, potentially 2414 radars, not including spares) is procured as one unit and savings from buying large quantities are possible -- as much as 904 million dollars, as shown in Figure 4-14. If LRUs and SRUs are standardized, certain LRUs will not be standard but will vary among MDSs. Figure 5-1 shows the architecture of the CMMR as projected by ASD. As presently envisioned, only the programmable signal processor and computer would be completely standard or common to all MDSs. However, at the SRU level, even nonstandard LRUs could have a considerable degree of commonality.

Figure 5-2 shows the common SRUs (shaded) hypothesized in the ASD Study. On the basis of cost data generated during that study, the programmable signal processor and radar computer make up about 52 percent of the total system cost. The remaining system cost is for the antenna, transmitter, and receiver-exciter.

For lack of more detailed data, we assumed that the cost of an LRU is equally divided among its component SRUs. We also assumed two-fifths of the transmitter cost to be attributed to nonstandard SRUs, and one-fourth of the receiver-exciter cost to be from nonstandard SRUs, since those fractions of nonstandard SRUs were found in these LRUs. To be conservative, we assumed that the entire antenna subsystem was composed

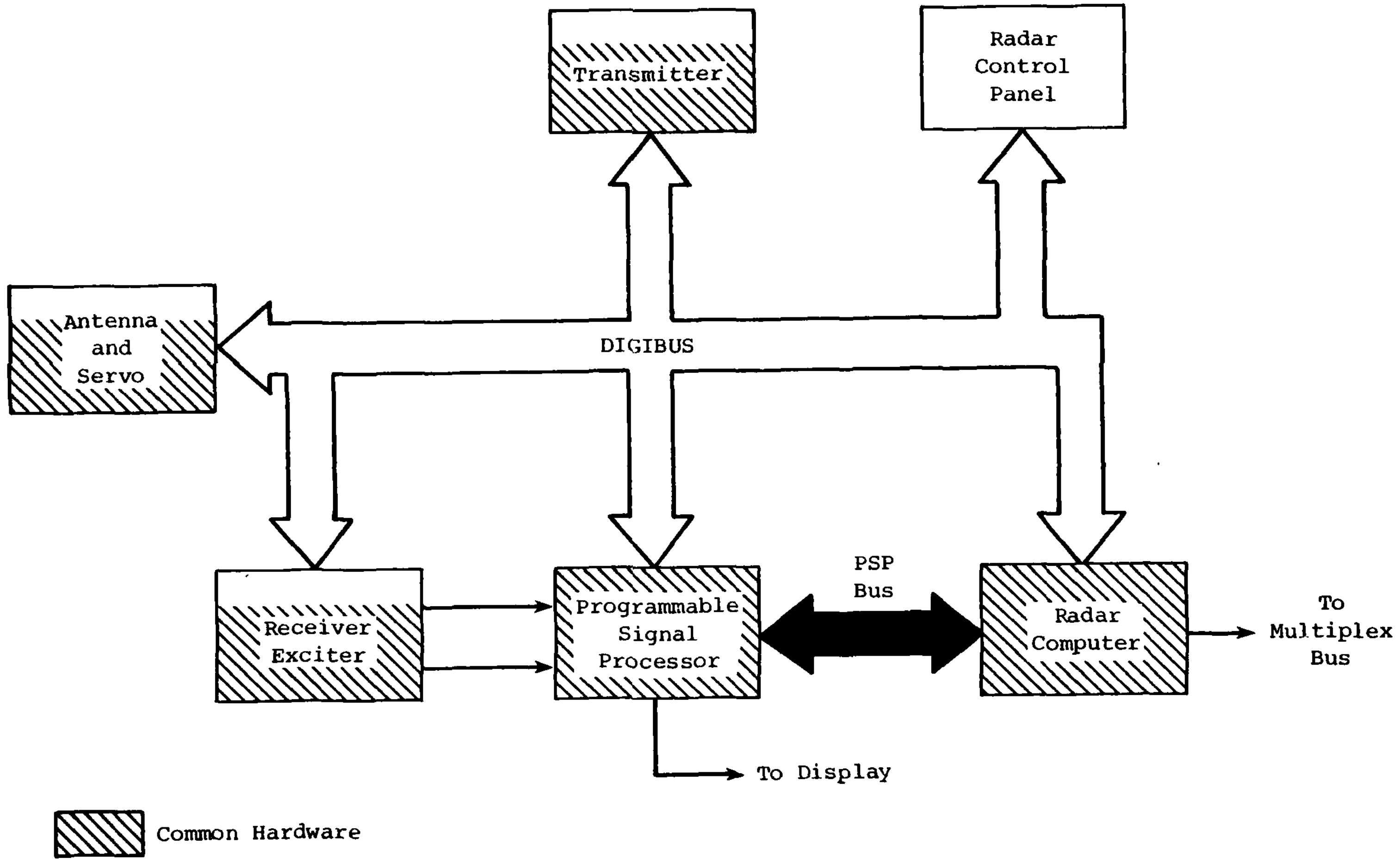

Figure 5-1. CMMR LRU CONFIGURATION

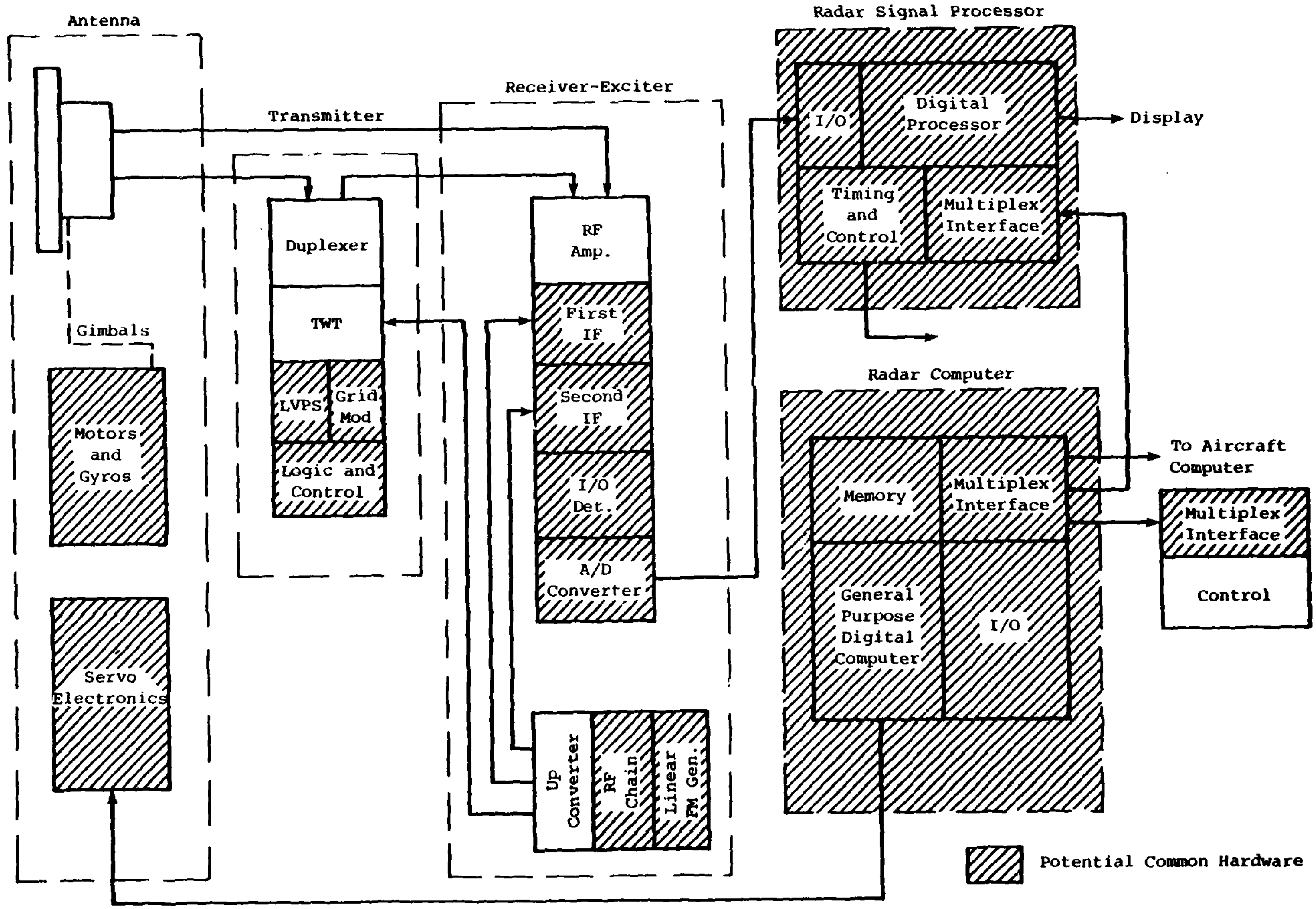

Figure 5-2. HYPOTHESIZED COMMON SRUs

of nonstandard SRUs. When all these nonstandard costs are summed, they represent approximately 20 percent of the total radar cost, according to the ASD data provided. Hence, the hypothetical CMMR is assumed to be composed of two standard LRUs and some standard SRUs, which represent 80 percent of the cost, and nonstandard SRUs, which represent approximately 20 percent of the cost.

5.2.2 Estimated Acquisition Cost Increases

The nonstandard SRUs have been estimated to cost approximately 20 per cent of the total unit cost. By using the cost method used for the 2,414 CMMRs (total potential market) developed in Chapter Four, we can approximate the cost of the nonstandard SRUs. Average unit costs for unique SRUs for each aircraft are obtained by separate calculation after entering the assumed 90 percent learning curve. Summing these individual costs provides the total "unique SRU" costs. (If these SRUs were not unique but could be purchased as one lot of 2,414, the total cost would be lower as a result of the greater learning curve advantage.) The difference (in 1979 dollars) is an estimate of the increase in procurement cost with LRU and SRU standardization as compared to system standardization, as shown in Table 5-1.

Table 5-1. LRU AND SRU COSTS

Aircraft	Quantity	Overall Unit Cost (Thousands of Dollars)	Unit Unique SRU Costs (Thousands of Dollars)	Total Unique Costs (Millions of Dollars)
F-16	678	550	110	75
F-4	648	560	112	73
F-106	209	665	133	28
F/FB-111	351	615	123	43
B-52G/H	528	578	115	61
Totals	2,414			280
If bought in total:		458	92	222
Difference				58

There should be an additional cost included during development, to ensure that CMMR system design allows for LRU and SRU standardization. The development costs assumed for the F-16 in the ASD Study (64.4 million), for example, do not specifically include this approach. We have assumed that this subsystem standardization approach would increase development costs by 25 percent or approximately $16 million. Added to the $58 million

increased procurement cost, the total cost of SRU and LRU standardization is estimated at 74 million constant 1979 dollars. This compares to a potential standard system costs savings over a separate radar and separate aircraft approach of $499 million in constant 1979 dollars ($904 million then-year dollars). The conservative estimate of the expected economic effect of LRU and SRU standardization for the assumed market size is that it will achieve approximately 85 percent of the potential savings calculated for full system standardization.

5.2.3 Management Pitfalls

In the limited or LRU and SRU standardization approach, the Government assumes possible additional risk in at least two ways. If the Air Force were to have a very well developed specification for CMMR, RFPs or RFQs could be solicited for individual LRUs or SRUs; although this has the advantage of maximizing competition, it could also produce a schedule delay because separate procurements would be involved. Even if time were not critical, the Air Force should recognize the large technical and management risk it would assume by becoming the integrator of all the LRUs and SRUs into the radar system for each candidate aircraft. On the other hand, the Government can reduce this risk by soliciting a single contractor to produce all the LRUs and SRUs required and act as integrator for all aircraft. In this case, competition would be limited to the initial solicitation. Even though the quantity-buy benefits would be maximized, total program costs might not be lowered. This approach is discussed further in the next chapter.

5.2.4 Summary

In summary, any radar hardware standardization should be limited to those LRUs and SRUs that are technically well understood and are architecturally discrete. Under this approach, we estimate that approximately 15 percent of the acquisition cost savings that would be achieved by full system standardization would be lost. Additionally, the Government would have to decide whether to accept reduced competition by allowing a single contractor to produce all LRUs and SRUs required and perhaps perform the aircraft integration task, or to accept the technical and management risk of performing the integration role in return for increased competition.

5.3 SOFTWARE STANDARDIZATION

The standardization of radar hardware at either the system or LRU and SRU level would be considerably less attractive if it were not for the flexibility provided by airborne radar data processing. With a radar computer and a programmable signal processor, each common radar can now be configured to perform a radar task that might be peculiar to that host aircraft. The vehicle for this variable configuration is the radar software or computer programs and instructions that direct the computer and signal processor. The software has a very significant effect on the system architecture, as well as a significant (although as yet not well quantified) effect on the total development cost.

Costs can also be reduced through software standardization just as they can from hardware standardization. Obviously, one set of system software, perhaps the set for the F-16, cannot be used in its entirety for the F-4E because of their differing missions and avionics interfaces. However, just as certain LRUs and SRUs can be standardized throughout the market, there may be certain software algorithms and support tools that can also be standardized. Because fully developed software is not a recurring production item, the advantages of software standardization lie in development cost savings and potentially lower support costs. As indicated in our review of the current radar technology programs, there is considerable proliferation of technology efforts in this area now.

The potential development costs savings of standardized software are dependent upon the number of different MDSs. Standardized software is more costly to develop than unique software because it has to consider a wide range of requirements. In order to be practical, standard software must be modularized and this requires that the interfaces between the software modules be very well defined. Although unique software can be rapidly developed under a "brute-force," totally integrated approach, this may not be as efficient during test, debug, and modification. The initial cost of a unique software package may be lower than that of a modularized software package; however, when the cost of subsequent modifications is added, the price of unique software is no longer as attractive. For N different aircraft models, N unique software packages would be required for the non-standard case. For modularized software only one core package would be needed for all aircraft. It would be adapted and modified to suit the particular requirements of individual aircraft types.

A factor that could reduce potential standard software development cost savings is the support cost for the unique Operational Flight Programs (OFPs). In addition, the cost of trainers, simulators, standard compilers, standard libraries, configuration management procedures, and other tools to upgrade and maintain existing facilities for CMMR could well dwarf any LCC advantages. These factors are not well quantified for CMMR, and additional study should be undertaken to understand better the potential benefits and risks of software standardization as applied to CMMR.

5.4 IMPACT OF STANDARDIZATION ON SUPPORT EQUIPMENT

One of the benefits of standardization could be a reduction in support equipment costs. In our study we did not attempt to quantify such savings, but used the ASD constant per-operating-unit support-equipment cost of $1.7 million on the basis of a present contract price. Support-equipment savings from standardization will accrue as a result of several factors.

There are learning curve benefits not considered in the estimates we used for our trade-off analyses. Rather than buying 10 to 20 units of each of 5 to 7 different types, the Air Force could make one large procurement of 50 to 100 sets. Thirty to 35 percent savings could be expected for a 90 percent learning curve. A second source of support-equipment savings

from standardization would accrue from sharing intermediate facilities. For example, a number of bases may have both a B-52 squadron and an F-106 squadron. At those bases, a centralized intermediate maintenance facility might be established with standardized radars and radar support equipment, to handle both F-106 and B-52 radars, although recent Air Force actions favor decentralized maintenance.

5.5 IMPACT OF STANDARDIZATION ON SPARES COSTS

Standardization can reduce spares cost through several mechanisms. First, the total quantity of spares required can be reduced. This could occur where several types of aircraft are being supported by the base and a minimum spares set is required for each type of aircraft. Under standardization, the base might no longer need a set of spares for each aircraft type. CMMR does not, in most bases, fit under this description, because we have assumed that only a few bases would have multiple aircraft types equipped with CMMR. The second mechanism of spares cost reduction occurs on the macro level rather than the micro, or base, level. If spares are being purchased for five or six different aircraft and each aircraft has a radar standardized to some level, spares for all the aircraft can be bought in one package, thus assuring significant learning curve savings over the nonstandard approach. This type of savings can be expected for CMMR, but additional study would be required to quantify the potential.

5.6 SUMMARY

In addition to the savings that might accrue from hardware standardization (at either the system or LRU and SRU level), additional cost benefits can be achieved through the development of common software and support equipment and buying of common spares in quantity. These potential savings have not been included in our payback estimates. In undertaking any of the standardization alternatives below full system standardization, there are technical and management risks to the Air Force that cannot be quantified. However, we believe that the planned scope of the CMMR is sufficiently large to warrant consideration of these alternatives:

- LRU and SRU Standardization
- Selected Software Standardization
- Support Equipment Standardization

CHAPTER SIX

DEVELOPMENT OF ACQUISITION STRATEGIES

6.1 INTRODUCTION

Our trade-off analyses have considered that the attractive acquisition alternatives are driven principally by the importance that the Air Force attributes to operational advances in radar technology proven through comprehensive development and flight test, acquisition cost, quantities, schedules, and availability characteristics of radars in production today. These key factors are presently being reviewed by the Air Force. This chapter will review the potential advantages and disadvantages of the primary acquisition approaches available and highlight related support considerations.

6.2 MANAGEMENT CONSIDERATIONS

In order to simplify the presentation of alternatives available to the Air Force, acquisition of CMMRs can be categorized by stages. The first stage includes engineering development and testing of one or more prototype systems. The next stage includes the procurement of some specific quantity of common production hardware and software from a contractor chosen at the end of the development and test stage. Assuming that the common radar hardware and software design is well understood and frozen during this stage, a third stage of follow-on buys could be anticipated if the market size is large enough. This would involve acquisition of additional systems from the same manufacturer and/or one or more others.

Subsets of these last two stages are also possible. There might be an additional manufacturer involved during the initial production stage because of critical delivery schedules. This manufacturer could be teamed with the first and share the work. He could be directed to produce identical systems or some quantity of identical subsystems. Or he might be a separate integrating contractor responsible primarily for installation and software.

Another possibility might be a separate buy after the development and test stage for which a second manufacturer produces a lesser-capability CMMR for some aircraft applications. This is similar to the split-buy approach analyzed in Chapter Four in which two manufacturers with

operationally equivalent radars but different designs were funded in parallel during and after the development and test period. This approach does not meet the intent of a common radar for all applications, but it is mentioned because two different systems can still provide sizable program cost benefits if several aircraft types are involved. If the market is large enough and the buy time must be as short as possible, as many as four major manufacturers (two teams of two each) might be required.

Decisions involving procurement of different or identical systems and teaming, leader-follower or acquisition strategies for split-buying must be made quickly to preserve the market. Although nonidentical split-buying has the advantage of keeping competitive interest alive, it has the disadvantage of increased costs for support equipment, training, and sparing. If a nonidentical split-buy procurement (rather than a teaming or leader-follower approach) is made to accommodate more than one aircraft, it would be desirable to split the award by aircraft type to reduce the logistics cost effects of the mixing of equipment from different manufacturers with different aircraft. Identical smaller buys brought about by a leader-follower or separate LRU approach reduces the learning curve savings.

When a firm market is established, the decision on whether and how to award two or more contracts should be based on (1) an assessment of whether the additional initial cost can be offset by reductions in downstream acquisition and/or logistic costs, and (2) judgment on whether any subsequent competitions can be favorably affected.

Two checklists have been developed to help the reader understand the information required and some of the difficult decisions that will have to be made by the Air Force during these early stages of the CMMR Program. Most of the items on these checklists have been raised previously as issues by Air Force planners. Those which have been considered in detail are indicated by a check (✓). A firm CMMR decision is still pending.

CMMR PREDEVELOPMENT PHASE CHECKLIST

- Perform initial requirements review
  - Assess present and future threat ✓
  - Determine present and future operational needs (including AMRAAM)
- Review current radar technology programs and synchronize efforts
- Determine capability of current production equipment to meet needs
  - Determine equipment baseline of current production radars ✓
  - Decide whether to meet all known requirements at the outset or "grow" equipment after initial development ✓

- Determine potential aircraft applications
  - •• Review market size ✓
  - •• Decide on CMMR or other modification programs for some or all aircraft and determine whether to include F-106 in CMMR Program
- Determine development strategy
  - •• Perform initial review of funding available (development, production, O&S) ✓
  - •• Decide whether to go sole-source or competitive (dual source or full) and decide if two nonidentical systems have merit
- Perform initial review of production strategies ✓
- Perform initial review of support concepts (RIW, LCC, etc.)
- Develop RFP(s) or contract amendments
  - •• Establish hardware and software requirements and goals (MTBF, costs, etc.)
  - •• Prepare specifications ✓
  - •• Determine number of prototypes required
  - •• Determine extent of Air Force involvement and influence during design
  - •• Determine data requirements
  - •• Determine flight test requirements and source selection criteria needed to select winner if procurement is competitive

CMMR DEVELOPMENT PHASE CHECKLIST

- Update candidate aircraft cost trade-off analyses to optimize CMMR installation schedules after thoroughly reviewing capabilities of existing radars, planned modification programs, and funding available
- Designate aircraft for CMMR Program
- Establish firm CMMR market size
- Perform detailed review of operational requirements of aircraft selected to ensure that CMMR development hardware and software will meet present and future needs
- Analyze interface requirements of selected aircraft to limit subsequent hardware and software modifications
- Ensure transfer of technology when needed for use during development and flight test
- Study effect, if any, of other Air Force standardization efforts (core avionics, standard computer, MATE, etc.) on CMMR
- Confirm system and LRU hardware and software designs and maintain control of configuration

- Perform detailed CMMR LCC/RIW analyses to clarify support concept
- Determine optimum method for procuring required production quantities of CMMRs
- Select production strategy
  - Single production contractor
  - Prime with directed sharing
  - Two or more prime contracts
  - Separate LRU buys with integrating contractor
- Select support strategy
  - Initially organic or LSC commitment
  - ICS to organic
  - RIW or RIW/MTBF to organic
- Develop production RFP(s)
  - Determine data (reprocurement?) requirements
  - Incorporate support provisions

As indicated by the predevelopment and development checklists most issues have not been resolved. An overall CMMR Program decision table has been developed and is presented as Table 6-1. Included in this table is the final major program stage -- logistics support.

Table 6-1. CMMR DECISION TABLE

How to Develop	How to Produce	How to Support
Requirements • Meet All Aircraft Now? • Grow Equipment? • Different Systems? Specification • Functional? • Performance? • Full Design? Number of Contractors • Sole Source? • Limited Sources? • Full Competition?	Single Manufacturer? Teaming Approach (Directed Sharing)? • Percentage of Contract Funds? • Hardware/Software? • Specific LRUs? • Leader/Follower (Identical Systems)? Split-Buy (Two Prime Contracts with Government)? • Identical Systems? • Different Systems? Separate LRU-Buy with Integrating Contractor?	Initially Organic or LSC Commitment? ICS to Organic? RIW or RIW/MTBF to Organic? • System RIW? • LRU RIW? RIW (No Transition)?

6.3 ACQUISITION STRATEGIES

Three acquisition strategies are analyzed: sole-source, dual-source, and full competition. All three strategies begin with events in February 1980, and involve varying degrees of development before production. Several procurement methods (leader-follower, teaming, and separate-buy) are also discussed. The initial support concept whose costs are included as part of the acquisition costs is discussed in the next section.

Table 6-2 presents a summary of the advantages and disadvantages of the three strategies discussed based on our trade-off analyses and other qualitative considerations.

Table 6-2. CMMR ACQUISITION STRATEGIES

Strategy	Advantages	Disadvantages
Buy a Current Production Radar (Sole-Source)	• Maximum Market Possible from Schedule Viewpoint (Earliest Schedule) • Lowest Development Costs • Proven Design	• Little Technology Transfer • Will not Meet all CMMR Requirements • Program Life-Cycle Costs Not Well Developed • Eliminates Competition Very Early
Develop a Full-Up CMMR (Full Competition)	• More Time to Trade-Off Technical Requirements • Develops Most Capable Radar • Maximum Technology Transfer Possible • Minimum Technical Risk • Most Flexible	• Highest Development Costs • Longest Schedule • Misses Some of Market • Might Not Be Most Cost-Effective Program
Modify an Existing Design and Grow (Dual-Source)	• Allows Time for Some Technology Transfer • Maintains Competition and Still Meets F-16 Schedule Effectivity	• Source Selection Might be Difficult • Concurrent Development and Production Likely

6.3.1 Sole-Source Procurement

With the knowledge of the existing radars in production (Hughes F-18, F-15, F-14, and Westinghouse F-16) and notwithstanding ASPR guidance, it would be possible to procure one of these radars as a common radar for all

or some of the candidate aircraft. Although none of these production radars presently contains all of the projected CMMR operational modes, a sole-source procurement has at least two distinct advantages -- lower development and more easily understood initial unit costs, and F-16 schedule effectivity. A major disadvantage is that it eliminates competition before full determination of operational and technical requirements, the total market, and thus the total program costs. Without knowing exactly how many modes will be common to the candidate aircraft, sole-source procurement could lead to undesired major modification programs later.

Sole-source procurement of existing production equipment would undoubtedly provide initial hardware ahead of any other procurement approach by at least one year. Actual schedules depend on decisions concerning the amount of modification (if any) desired to the radar selected, the quantity of radars involved, and the lead time required for critical components, in addition to any effect on the schedule by radars required for delivery by the manufacturer to other non-CMMR programs.

If for some reason such as operational needs or critical schedules, sole-source procurement is necessary, the Air Force should seriously consider the possibility of acquiring reprocurement data in order to provide decision-makers the flexibility to develop a second source later, when total CMMR program costs using this approach are better understood.

6.3.2 Fully Competitive Procurement

We reviewed an ideal fully competitive acquisition program, meeting the needs of all candidate aircraft within the basic development and production program. This postulated program, to be initiated in February 1980, requires 12 months for the drafting of an RFP, during which time additional aircraft studies are performed to ensure full understanding of all the candidate aircraft operational and technical requirements. Group A and B requirements for all aircraft are analyzed and trade-offs are performed to determine optimum hardware and software specifications. This program would develop the best set of CMMR specifications possible and fully identify both the hardware and software objectives. Competition would be open to any manufacturer.

The result of the first stage of this program would be the development of competitive hardware and software to optimize a CMMR for several applications. This program might be structured to sacrifice some of the more expensive requirements that fit the needs of only one or two aircraft applications for the sake of hardware and software commonality and standardization at the outset. It would use a building-block approach and trade-off cost against operational requirements, perhaps even dropping some for the benefit of the overall program. It also waits for maximum technology transfer and emphasizes program life-cycle costs.

Figure 6-1 shows a schedule for this program with first production hardware being delivered in July 1986. Enough time is allowed (18 months for design and fabrication, 12 months for flight testing) for the selected

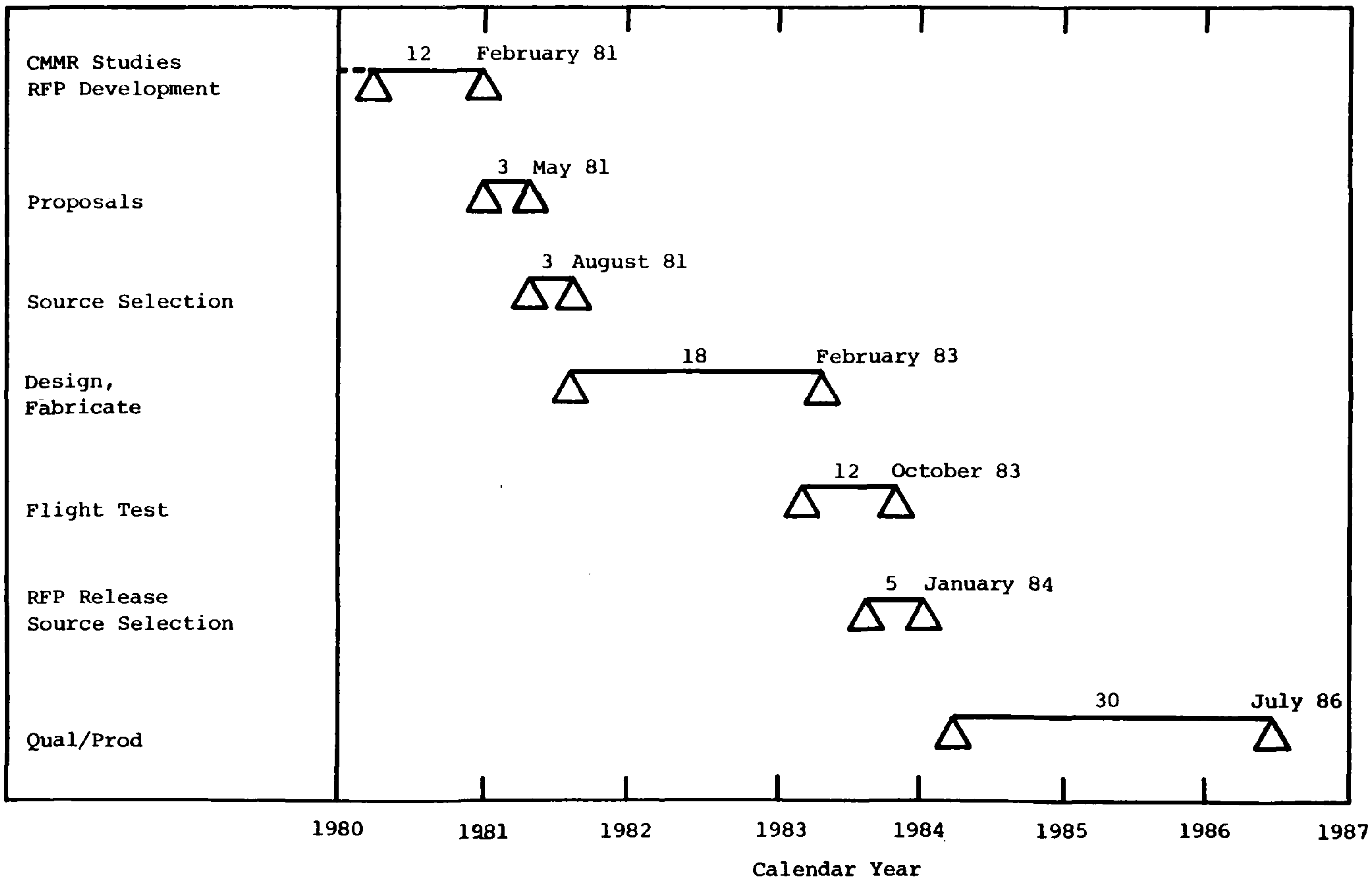

Figure 6-1. CMMR PROGRAM FULL COMPETITION PROCUREMENT STRATEGY

modes of a CMMR to be fully developed and tested before a production decision is made. During the flight-test phase, a second RFP would be developed for the production phase. The equipment qualified and produced would be available for one or more aircraft approximately 30 months after source selection. Second-source procurements, if needed because of market size, could be considered.

The program would require the longest and most expensive development. This approach minimizes technical risk; however, it assumes few, if any, installations in F-16 and F-106 aircraft. It would have more flexibility than the sole-source approach, since it would involve competitive manufacturers who will have designed their systems to meet all known CMMR requirements.

6.3.3 Dual-Source Procurement

A third possible acquisition approach, dual-source, has been proposed by ASD. A procurement schedule is shown in Figure 6-2. Previously discussed in Chapters Three and Four, this program, which would meet the operational and schedule needs of the F-16, could allow for production deliveries beginning in mid fiscal 1984 (beginning approximately with production aircraft number 710), two years ahead of the fully competitive program. Unfortunately, this program is too short to develop a full-up CMMR and will require additional growth, primarily through software changes, in order to meet all known and anticipated CMMR requirements.

The F-16 SPO is currently embarked on an effort to develop and flight-test two candidate radars. Both radars will have the potential of being used in common radar applications; however, due to limited funds and the short schedule, the initial flight test program involves only the following:

- One candidate will consist of a modified Westinghouse F-16 radar with a PSP and a dual-mode transmitter for increased detection range. The flight-test program would test all current F-16 modes, plus at least the new track-while-scan and raid-assessment modes. The PSP hardware would be sized for application in TF and SAR modes along with new ECCM modes.
- The other candidate will be the Hughes APG-65, presently flying in the F-18. ASD has stated that the APG-65 is already compatible with all F-16 requirements and no new modes would be developed under the competitive development phase of the program. All existing APG-65 modes would be tested before source selection.

At the end of this stage of the program, it is envisioned that two systems fully integrated with the F-16 will be developed and flight-tested. Additional radar modes and other aircraft capabilities would then be flight-tested as required or desired while the F-16 qualification and production program is under way.

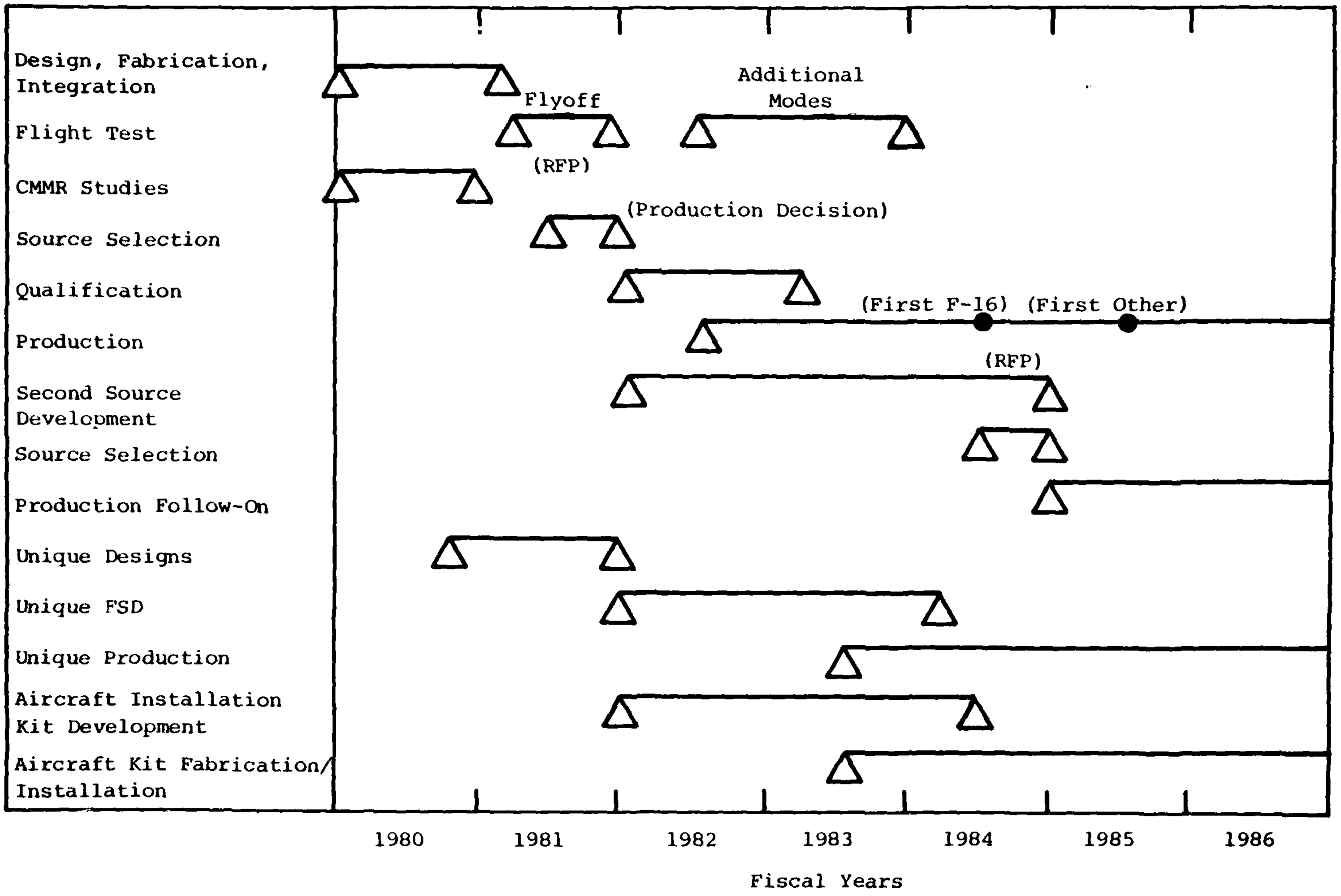

Figure 6-2. CMMR PROGRAM DUAL SOURCE PROCUREMENT STRATEGY

AD-A116 934 ARINC RESEARCH CORP ANNAPOLIS MD F/G 17/9
DEVELOPMENT OF ACQUISITION STRATEGIES FOR THE COMMON MULTI-MODE--ETC(U)
JAN 80 E STRAUB, J BAILEY, R GILBERTSON F09603-78-G-4125
UNCLASSIFIED 1564-11-1-2122 NL

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In fiscal 1982, after the winner of the competitive fly-off has been selected, the program could be expanded to include production CMMRs for the other candidate aircraft. The CMMRs would be initially installed in other aircraft after qualification testing, approximately one year later than in the F-16. How these additional radars are to be procured remains undecided, although current Air Force thinking appears to favor the development of a second source for the remaining candidate aircraft if the market is large enough. This approach calls for development of one RFP for the production phase to be released at the outset of the initial flight-test program.

6.3.4 Leader-Follower Approach

The development of a second source for major DoD acquisition is not a new concept. Reprocurement data can be used to permit a competitive follow-on buy for a mature product. This method should not require assistance from the original source. Developing a second source under a different (leader-follower) approach can also be used to introduce competition for price or for technical reasons. The intent would be to force the original source, as well as the second source, to become as efficient and innovative as possible, to assure the Air Force of the lowest cost procurement that is practical.

The ASPR clearly spells out the rationale and procedure for use of a leader-follower concept:*

> "Leader company procurement is an extraordinary procurement technique under which the developer or sole producer of an item or system (the leader company) furnishes manufacturing assistance and know-how or otherwise enables a follower company to become a source of supply for the item or system. This technique is used to accomplish one or more of the following objectives:
>
> (i) shortening the time for delivery;
>
> (ii) establishing additional sources of supply for reasons such as geographical dispersion or broadening the production base;
>
> (iii) making maximum use of scarce tooling or special equipment;
>
> (iv) achieving economy in production;
>
> (v) assuring uniformity and reliability in equipment performance, compatibility or standardization of components, and interchangeability of parts;
>
> (vi) eliminating problems in use of proprietary data not amenable to other more satisfactory solutions; or

---

**Special Types and Methods of Procurement, Part 7 - Leader Company Procurement, Armed Services Procurement Regulations*, 4-701, 4-702, 4-703.

(vii) effecting transition from development to production and to subsequent competitive procurement of end items or of major components.

"Limitations on Use. Leader company procurement is to be used only when all of the following circumstances are present:

(i) the leader company possesses the necessary production know-how and is able to furnish the requisite assistance to the follower;

(ii) no source of supply (other than a leader company) would be able to meet the Government's requirements without the assistance of a leader company;

(iii) the assistance required of the leader company is limited to that which is essential to enable the follower company to produce the items; and

(iv) the Government reserves the right to approve contracts between the leader and follower companies.

"Procedures.

"(a) One procedure is to award a prime contract to an established source (leader company) in which the source is obligated to subcontract a designated portion of the total number of end items required to a specified subcontractor (follower company) and to assist the follower company in that production.

"(b) A second procedure is to award a prime contract to the leader company for the requisite assistance to the follower company, and another prime contract to the follower company for production of the items.

"(c) A third procedure is to award a prime contract to the follower company for the items, under which the follower company is obligated to subcontract with a designated leader company for the requisite assistance."

This technique might well be used when a single manufacturer's production capacity is limited, the items and delivery schedules are critical, a long production run is anticipated, and the negotiating position might be weakened because of a sole-source (proprietary rights) situation.

On the other hand, some of the drawbacks to the leader-follower concept are these:

- Costs to qualify a second source may exceed savings that future competition may yield. These include costs of unique and

additional tooling required and of reprocurement rights if the Government does not own the data.

- The leader may not fully provide know-how and assistance to the follower or it may not have identified and resolved its own production problems.
- Configuration control may be difficult to maintain. It is mandatory that the Government have qualified technical personnel to assist the second source, particularly at the outset or during the initial production phase.

From the above discussion it is evident that the leader-follower technique requires a long production run of substantial quantities to warrant the expense of qualifying a second source. It is also more appropriate for well established, less complex items, for which an extremely good technical data package is available and manufacturing knowledge would be easy to transfer. There must also be sufficient lead time to develop an interested second source and assign qualified DoD technical personnel to assist the follower in tooling up for production.

6.3.5 Teaming Approach

The intent to use a leader-follower concept should be announced as a Government option for production prior to competitive development. With the dual-source approach presently proposed by ASD, two competing manufacturers are already producing different high-technology systems for current production aircraft. Our understanding of the status of the production hardware and software of both manufacturers and the number of changes necessary for the CMMR suggests that it is now too late to attempt to use the "normal" leader-follower approach to develop a second source (procurement of a reprocurement data package and technical assistance from the prime). The cost of the attack radars of the future are driven primarily by the costs associated with the high technology PSP and computer LRUs and their software development, a technology that is not easily transferable and might create proprietary rights issues.

There is another alternative to the leader-follower approach to sustain a competitive base. It involves the forcing of a prime manufacturer to share some of his work with a second source. This sharing could involve the following:

- A specified percentage of the dollar amount of the contract
- Direction that a second manufacturer produce a specific portion of the system, such as the computer or receiver
- Responsibility for specific roles in the program, such as installation contractor, developer of the support equipment, etc.

The key to any teaming concept is that the second manufacturer would be directly involved in the engineering design and production of the system, because without him the system could not be produced, installed, or

maintained. An approach in which the second source would produce subsystems identical to those produced by the prime contractor might not provide enough incentive to the prime to ensure success or the required quantity of systems.

An extension of this approach might be to have the second manufacturer responsible for the nearly identical systems required for aircraft other than the F-16. Provided that similar hardware and software are required for all systems and the prime is held responsible for ensuring that the requirements for all systems are met, this approach might also work.

6.3.6 Separate LRU Buys with an Integrating Contractor

Another approach to procuring a CMMR could be to contract separately for the individual CMMR LRUs (receiver, transmitter, computer, etc.). For the quantities involved, it would be reasonable for the Air Force to solicit competitive proposals for production of each of the LRUs. The design of the CMMR is not yet frozen and will not be until after the second series of flight tests, when the dual-source winner already will be producing F-16 radars. This approach would further require either that the Government play the role of integrating contractor or that there be another installation and integration contractor. If the CMMR matures as anticipated over several years, and the hardware design is eventally frozen so that only software changes would be required to accommodate the changing threat or for other operational needs, separate buys of standardized LRUs will then be very attractive.

6.4 SUPPORT STRATEGY

The CMMR payback for the candidate aircraft is very sensitive to current radar logistics support costs and estimated future CMMR logistics support costs. The success of the CMMR program is predicated on the development of a common radar with an MTBF of 50 hours. This will be an ambitious undertaking, since at the present time none of the existing radars for candidate aircraft have exhibited MTBFs approximating this.

Table 6-3 expands the support strategies presented in Table 6-1. The three support strategies indicated are provided to assist the reviewer in understanding some of the factors to be considered on the subject. A fourth strategy, Reliability Improvement Warranty (RIW) without transition, is also possible. Since it would only be used where there would be no need for a depot capability (short life expectancy), it was not considered to be a plausible alternative.

6.4.1 Initially Organic or LSC Commitment

If the CMMR hardware design were well understood and the support equipment requirements well known, it would be possible to plan for organic maintenance at the outset. However, an initially organic strategy of itself does not provide incentives to control support costs. A logistics support cost (LSC) commitment is a means of controlling an equipment's support costs when an organic support concept is initially required. Under this

Table 6-3. CMMR LOGISTICS SUPPORT STRATEGIES		
Strategy	Pros	Cons
Initially Organic or LSC Commitment	• Offers Maximum Operational Flexibility • Offers Maximum Utilization of Government Personnel and Facilities • Requires Minimum Spares	• Includes Data and Software That are not Mature and are Costly to Change • Develops Hardware and Support Equipment Concurrently • Results in High Government Inventory Management Costs
ICS to Organic	• Provides for Early IOC • Assures Availability of a Pool of Contractor Expertise • Allows Time for Data and Software Maturity	• Requires Support Costs that may be Difficult to Forecast • May Require Extra Facilities • Results in Contractor Dependency
RIW or RIW/MTBF to Organic	• Defers Initial Support Investment • Keeps Government Inventory Management Costs Low • Makes Available Skilled Personnel • Provides Incentive to Grow Reliability • Allows Time for Support Equipment to Mature • Provides Flexibility for Equipment Improvement	• Carries Possible Operational Constraints • Requires Back-Up Facilities • Requires "Front End" Financing for Sparing at LRU Level • Results in Warranty Costs that Might Exceed Benefit

plan the contractor makes a contractual commitment regarding a specified LSC parameter, which is quantified through the LSC model. A controlled operational field test is subsequently performed to acquire data for the key variables in the model. The measured LSC parameter is then compared with the contractually specified or target value.

This strategy offers maximum operational flexibility, because the user controls sparing, turnaround times, etc. This flexibility is very important to some using commands, especially SAC. One of its disadvantages is that it requires the concurrent development of unit hardware and support equipment.

6.4.2 Interim Contractor Support (ICS) to Organic

If some radar system growth and changes to AGE were anticipated, ICS might be the best approach for some specific period of time. This strategy provides for an early initial operational capability (IOC). However, this strategy must be planned to avoid prolonged dependency on the contractor. Under ICS, the contractor may use more experienced technicians and less expensive factory test equipment while the software and hardware end-items are maturing.

6.4.3 Reliability Improvement Warranty (RIW) or RIW/MTBF to Organic

An RIW plan commits the contractor to perform stipulated depot-type repair services for a fixed operating time, calendar time, or both, at a fixed price. While the major expenditures of a warranty procurement are for the repair services involved, the prime thrust of the approach is to achieve acceptable reliability. The question of whether the contractor can provide depot repair services at a cost lower than that of military repair is secondary to the objective of reliability achievement and reduced support cost.

Reliability improvement warranties are negotiated in association with the production contract and apply to the operational use of the production items. Because of the long-term commitment being made by the contractor, warranty service is recognized as a separate cost item that the prospective contractors are asked to quote as a separate line-item option. This provides the Government the opportunity to evaluate the costs of the warranty versus nonwarranty procurement, with consideration given to the reliability and maintainability differences between the two alternatives. Warranty funds have been obtained from both production and operation and maintenance sources. If operation and maintenance funds are to be used, incremental funding for long-term warranty is necessary because this fund category can be committed on an annual basis only. Under an RIW plan, the acquisition of support equipment is normally deferred until the end of the warranty period. The overall plan might carry some operational constraints.

The MTBF guarantee requires the contractor to guarantee that the equipment will experience a stated MTBF in the operating environment. If the guaranteed level is not met, the contractor is typically required to institute corrective action and to provide consignment spares until the MTBF improves.

The MTBF guarantee is normally procured in association with an RIW. An RIW plan provides incentive for MTBF achievement through the maintenance support commitment by the contractor. The MTBF guarantee provides an even stronger incentive because the contractor is obligated to provide consignment spares to relieve pipeline shortages that may result from low MTBF. The MTBF plan also includes requirements for improving the MTBF to stated values. The RIW and MTBF plans are considered totally compatible.

6.5 SUMMARY

Table 6-5 ranks the three CMMR acquisition strategies according to the criteria indicated. If any particular criterion dominates, any one of the three strategies might be selected. This highlights the need for timely decisions by Air Force planners. The strategy implied by overall considerations is full competition. Dual source represents a compromise position that may be required by expenditures, schedules, market size, and overall policy considerations.

Table 6-5. RANKING OF CMMR ACQUISITION STRATEGIES

Ranking Criteria	Strategy: Sole Source	Strategy: Dual Source	Strategy: Full Competition	Comments
REQUIREMENTS				
Operational				
CMMR	○	□	●	
F-106	●	□	○	Can Be Met Now
Technical				
Technology Transfer	○	□	●	
Growth Provision	○	□	●	
Aircraft Interfaces	○	□	●	Assumes More Than One Aircraft
ECONOMIC				
Development Costs	●	□	○	Less Than $50M Available -- Go Sole-Source
Production Costs	○	□	●	
O&S Costs				
Reduce Existing	●	□	○	
Optimum CMMR	○	□	●	
Optimum LCC				
< *1,000* Radars	○	●	□	*Sensitive to* Market and Aircraft Types
> 1,000 Radars	○	□	●	
SCHEDULE				
< 4 years	●	--	--	Only Sole-Source Possible
4 to 6 years	□	●	○	
> 6 years	○	□	●	
MANAGEMENT CONTROL				
Overall PGM Flexibility	○	□	●	
Development and Production Costs	○	□	●	
Change Number of Aircraft Types	○	□	●	
Accommodate Threat Change	○	□	●	Unless Needed Now

Criteria Ranking: Most Attractive ●
Moderately Attractive □
Least Attractive ○

CHAPTER SEVEN

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 SUMMARY

This report has been structured to help Air Force planners make the timely decisions that are required to determine the future of the CMMR Program. If the CMMR Program is given program go-ahead, it will one of the Air Force's most ambitious undertakings, an attempt to develop common radar hardware that will not only modernize the present aging fleet with more advanced equipment but also enable it to cope with a continually changing threat. Because of the sizable initial investment required and the numerous current technology, production, and modification programs affected, it is apparent that consolidation will not be an easy task. This is especially true of technology programs, for which better synchronization will be required if they are to be of any value to CMMR.

7.2 CONCLUSIONS

As shown during the analyses in Chapter Four, the CMMR benefits are potentially very large, as high as $900 million in acquisition cost savings alone if all the five candidate aircraft have a quantity of approximately 2,400 common radars installed. Payback for four of the five candidate aircraft could begin in the early 1990s. The analyses also concluded that these paybacks and the cost benefits are very sensitive to the existing radar logistic support costs and the anticipated reliability of the CMMR. Even if the market were reduced to approximately half, the cost benefits still appear to be sizable.

As pointed out in Chapter Six, before any specific CMMR acquisition strategy can be adopted, several key decisions are required. Final agreement must be reached on the CMMR operational requirements (operating modes). Technical requirements such as nuclear hardening also must be established. With the exception of the F-4E and F-106, all the candidate aircraft have the alternative of modifying existing hardware. While that alternative is not attractive from a cost standpoint, it would help the Air Force meet schedule demands. After CMMR requirements have been firmly established, the market size must be calculated more precisely because this will have a substantial effect on the acquisition strategy selected.

7.3 RECOMMENDATIONS

ARINC Research recommends that Air Force planners responsible for the CMMR effort take the following actions:

- Obtain a go/no-go decision on the F-106 Radar Upgrade and Modernization Modification (RUMM) program. AFLC has stated that the F-106 will be only "40 percent supportable" after fiscal 1985. The inclusion or exclusion of this aircraft is central to the acquisition strategy.
- Formally review all applicable 6.3 and 6.4 radar technology programs. Because these are generally not targeted for specific applications, the cognizant program offices have little awareness of their potential support to the CMMR Program. Offices at the AX level or above should review these programs and provide guidance, especially in relation to scheduling, where needed inputs must be synchronized.
- Determine program costs more precisely. In particular, software development and support equipment costs need further refinement. These are potentially very large segments of CMMR life-cycle costs.
- Decide which hardware procurement strategy to follow. As indicated in the conclusions of this report, the acquisition strategy selected is very sensitive to the market size. At this time it appears that the leader-follower approach would be unnecessarily risky. Teaming might be a viable approach if the market approaches 1,000 radars and an additional manufacturer is required for competitive or schedule reasons.
- Develop a software acquisition strategy. It is evident that with the extent of embedded computers in the architecture, strategies should be developed for the acquisition of software as well as hardware for the CMMR Program. This strategy should encompass the standards to be used (HOL, ATLAS, 1750, 1553, etc.) and the software support tools. A radar software focal point should also be established to monitor both the present technology programs and programs for the development of the CMMR signal processor and computer hardware.

APPENDIX A

RADAR SYSTEM DESIGN CONSIDERATIONS

1. INTRODUCTION

This appendix provides a general background to complement the discussion of alternatives developed in the main body of the report, as applied to pulse-doppler or moving target indication (MTI) radars. It is divided into three main sections: radar design, radar clutter and target detection, and radar operating modes.

2. MTI RADAR DESIGN

The primary purpose of any attack aircraft radar system is to search for, acquire, and track targets. A radar does this by transmitting some waveform of energy at a specified frequency in a selected direction and then determining the nature of the return energy (echo). During its search operation the radar scans a selected area, which is dependent on the radar mode selected. Once a target is acquired, the radar locks on to the target and its receiver generates antenna error signals. The error signals contain both azimuth and elevation data, which are used by the antenna control to keep the radar antenna pointed at the target being tracked. The antenna positioning and target range data are routed to other avionics systems, which compute solutions to the geometry problems associated with weapons delivery. A properly functioning aircraft radar can determine a target's velocity, range, and its angular direction. Additionally, an advanced radar can determine the target size and shape and whether or not the target shape is changing.

The ability of a particular radar system to detect targets with a desired accuracy and resolution is dependent upon a number of parameters that affect the radar design. These parameters include, but are not limited to, the transmitter power, antenna aperture, scan rate, antenna beamwidth, receiver bandwidth, and pulse width and pulse repetition frequency (PRF) for pulsed radars (or modulation bandwidth in CW radars). The optimization of any one parameter to enable the radar to perform in a particular mode unfortunately reduces the radar's performance when it operates in another mode. For example, an airborne radar with an air-to-air long-range search (LRS) mode requires high average power that can be provided by a high PRF, whereas a short-range search (SRS) mode might perform better with a medium PRF.

The modern airborne radar creates a number of conflicting requirements for the radar designer because the attack aircraft radar system must perform more than one mission in today's multicapability aircraft with its array of air-to-air and air-to-ground weapons. Modern warfare and supersonic aircraft have dictated that radars of the next decade must search farther and see clearer than radars of the past decade. The next generation of radars will be expected to automatically track both high- and low-altitude air-to-air targets with speeds ranging from supersonic to helicopter hover. This same radar will also be expected to operate in an air-to-ground mode and track or locate fast moving, slow moving, and fixed surface targets on land and at sea. This radar might also be expected to perform terrain-avoidance and terrain-following functions.

Table A-1 lists the various modes and submodes that are desired in a modern airborne attack radar. A brief explanation of each of these radar modes is given in Section 4. The conflict for the designer comes in selecting the various ways to provide the capabilities required, because they are not compatible with one another in terms of measurement accuracy, resolution, and clutter (unwanted signals) discrimination.

2.1 Radar Design Principles

A radar system operates by transmitting an energy waveform at some peak amplitude and given frequency and then measuring the amplitude, frequency, and time delay of the energy reflected (echo) from a target. Because of the presence of unwanted echos (clutter) in the radar's operating environment, the detection of a target is essentially a statistical process. For pulse systems, the probability of detecting a target is dependent on the number of useful echo pulses a radar detects. The more echo pulses detected, the more signal energy available to the radar processor to form an image. It is possible to detect a target on the basis of a single pulse, but this requires a radar designed to have a high signal-to-noise ratio.

Radar parameters must be variable in order to maintain a high probability of detecting a target whether it is in the air, on the ground, or at sea. Without the ability to vary pertinent parameters, the radar can be designed and optimized for only one mission and compromised for others, or compromised for all missions. With the rapid advances in computer technology and the advent of the high speed radar programmable signal processor (PSP), today's radar designer has almost unlimited flexibility to achieve capabilities over any single-mission radar system.

2.1.1 Radar Transmitters

The energy level of the return echo is dependent on the average transmitter power level. The average transmitter power level in a pulsed radar is in turn directly dependent on the peak power of the transmitter, radar pulse width, and PRF. The product of the pulse width and PRF constitute the radar's duty cycle. The higher the duty cycle required to detect and track a target, the more average transmitter power required. Peak transmitter power is constrained by the physical limitations of the

Table A-1. MAJOR RADAR OPERATIONAL MODES

Air-to-Air Modes	Air-to-Ground Modes
Air Combat	Ground Mapping
• Rapid Search	• Spoiled Beam
• Auto Acquisition	• Real Beam
•• Boresight	• High Resolution
•• Super Search	•• *Doppler Beam Sharpening*
•• Vertical Scan	•• Synthetic Aperture Radar
•• Auto Gun	• Freeze
• Auto Track	• Expand
Normal Air	Air To Ground Ranging
• Look Up	Ground Moving Target
• Look Down	• Fast Moving Target
• Manual Acquisition	• Slow Moving Target
• Single Target Track	Fixed Target Track
• Track While Scan	Ship Detection and Track
• Long Range Search	Navigation Update
• Velocity Search	• Position
• Range While Search	• Velocity
• Short Range Search	Terrain Avoidance
• Identification (IFF)	Terrain Following
• Non-Cooperative Target Recognition	**Special Modes**
• Raid Assessment	Beacon
Target Illumination	ECCM
Helicopter Detection	TV
	SNIFF

radar installation such as size or heat dissipation or the limitations on the effective antenna area (antenna aperture).

Radar transmitters may either operate continuously or provide pulses of energy. In a pulse radar, the transmitter will emit a short burst of energy and then turn itself off while turning on the receiver to listen for an echo. For the next burst the transmitter will turn itself on and the receiver off. In a continuous energy system, the transmitter and receiver are both operating continuously.

Pulse energy and continuous energy systems have several advantages and disadvantages when compared to each other. The continuous energy system is relatively simple, but one of the major disadvantages of a simple CW system is the amount of transmitter noise that finds its way to the receiver due to the continuous operation of both transmitter and receiver. Measures necessary to reduce the effects of transmitter leakage into the receiver introduce complexity, but can be used to provide excellent performance, expecially for weak-signal conditions. A major advantage of a pulse radar is the versatility obtainable. Its disadvantage is that it is much more complex and costly.

In order for either a pulse energy or continuous energy system to be effective, each must have some way to reliably and accurately detect the echo, even though the reflected energy waveform is considerably weaker than the transmitted energy waveform. For a modern airborne attack radar using moving target indication, this is acc mplished by making use of the doppler effect.

2.1.2 Doppler Shift

If there is relative motion between the tracking radar and the target, there will be a shift in the carrier frequency of the echo waveform. This frequency shift is proportional to the relative velocity between the tracker and the target. If the aircraft is closing on a target (separation decreasing), the echo waveform carrier will shift to a higher frequency as if the echo wave were being compressed. This movement in echo waveform carrier frequency is known as the doppler shift. It provides more than just a measure of relative velocity. It allows the receiver to discriminate between echoes and spurious energy introduced into the system by insufficient transmitter-receiver isolation or reflections from the radome, because these spurious signals will exhibit no doppler shift. Discrimination of this nature is very important for long-range targets, because their echoes are very weak and otherwise might be lost in the clutter if amplitude were the sole detection criterion.

2.1.3 Echo Returns

The number of echo returns during a given radar scan is directly proportional to three parameters--pulse repetition frequency (PRF), beamwidth, and scan time. Since the ability to detect and extract information about a target is dependent on the number of echo pulses that the radar sees in a

given scan, it would seem desirable to have as large a number of echo returns as possible. This is not the case however, because of the clutter attenuation and radar transmitter power levels associated with echo returns per scan. Clutter attenuation is directly proportional to the number of echo returns per scan. A radar optimized to detect ships at sea would not perform as well against land targets because of the difference in clutter attenuation required. The use of a higher power level to search for a low-flying bomber could result in the detection of a bumble bee. A complete discussion of radar clutter and target detection techniques used to counter clutter problems is contained in the next section.

The major problems associated with obtaining an adequate number of useful echo returns relate to the compromises that may be required in other areas of radar performance, since the three parameters associated with the number of echo returns per scan all affect other radar characteristics. The beamwidth influences both the resolution and accuracy obtainable in a radar. Narrow beamwidths result in improved accuracy and resolution; however, the magnitude of the beamwidth is dependent on the space available for the antenna. The narrower beamwidths require a larger antenna. The scan time is dependent on how often it is necessary to see a target. Since the scan time is the reciprocal of the antenna rotation rate, slowing down the antenna to increase the scan time will decrease the amount of information available concerning a fast moving target. Since the PRF is normally chosen to achieve a maximum unambiguous range, changing the PRF affects the accuracy of the range measurement. Still, because of the ease of doing so, the PRF is the parameter that is normally varied to optimize radar performance.

2.1.4 Pulse Repetition Frequency (PRF)

The radar PRF directly influences the quantity of echo returns per scan, the radar average power, the radar duty cycle, and the maximum unambiguous range of the radar. Additionally, since the PRF directly affects the number of echo returns per scan, which in turn affects clutter attenuation, the radar PRF may be considered to be directly related to clutter attentuation. This means that a radar can be peaked to detect a specific target in any given environment by selecting the optimum PRF available within the constraints of the remaining radar system design parameters. However, as mentioned earlier, optimizing the PRF to detect a specific target in any given environment compromises the radar's ability to detect the same (or other type) target in another operating environment.

2.1.4.1 High PRF Operation

High PRFs, which require increased average transmitter power levels, provide a high number of echo returns per scan. This increases the probability of separating a target from the clutter at the expense of target resolution and definitive range determination. In high PRF operation, additional pulses are transmitted before the original echoes return from a target. The radar is then unable to compare the echo return against the specific pulse transmitted because echoes are being received from many ranges simultaneously. This inability to separate incoming echoes on the basis of time delays causes range ambiguities.

A radar operating at a high PRF normally filters return echoes on the basis of apparent closing velocity. Because of the high duty cycle required, the high PRF modes are particularly susceptible to clutter in a region near the tracking aircraft. However, in the maximum range mode, velocity search, a high PRF radar can detect targets at ranges in excess of 150 nautical miles.

2.1.4.2 Medium PRF Operation

Medium PRF radar operation is normally used to enhance target resolution and make an accurate range determination. The lower duty cycle of a medium PRF radar allows the implementation of additional clutter-reduction techniques besides filtering, such as range gating. As a result of using clutter rejection techniques, such as those discussed in Section 3 of this appendix, target detectability is not as significantly influenced by clutter as in high PRF operation. Medium PRF operation allows targets to be detected and accurately tracked out to ranges in excess of 20 nautical miles.

2.1.4.3 Low PRF Operation

Low PRF radar operation is limited in its ability to attenuate clutter because of the reduced number of echo returns per radar scan. However, it is a useful operational feature for look-up situations, where there is no ground clutter, and in ground ranging and some ground mapping modes where it is necessary to see the complete image of the terrain.

2.1.4.4 Interleaved PRF Operation

Often an interleaved PRF will be mechanized in the radar because of the performance balance that can result from a combination of PRFs. Each PRF provides a strength corresponding to a weakness in the other PRF. The normal combination is an interleaving of high and medium PRFs.

The high-PRF radar gives excellent nearly clutter-free performance against high-speed closing targets by providing the high average power required to yield a long-range detection and tracking capability. The medium PRF has the necessary range resolution capability to separate target return from short-range clutter.

The normal mode of implementing interleaved PRFs is to alternate PRFs as the radar scans back and forth over a given area. Interleaved PRFs are particularly useful in the long-range-search or range-while-scan modes. The high PRF is used to detect the target and the medium PRF determines the unambiguous range.

2.2 Other Considerations

2.2.1 Frequency Agility

Another method used to assist in detecting targets is frequency agility (FA). FA transmissions employ a variety of pulse widths and PRFs to obtain

an improved display over that possible with single frequency techniques. The FA technique uses statistical averaging of return signals to give greater clarity and definition to the radar image. The quality of the return from the scattering elements of a complex target depends on the magnitude and relative phase of the individual echoes. Varying the radar frequency from pulse to pulse results in the return of a given pulse being uncorrelated with successive returns. By integrating the number of pulses for any one scan a relatively consistent response can be obtained. FA operation improves the sampling procedure since an average response is obtained in less time than is required in single frequency techniques. The FA technique not only provides an improved display, but also reduces mutual interference and the effectiveness of jamming.

2.2.2 Coherency vs. Non-Coherency

The echo signal of a moving target combined with clutter will vary in both phase and amplitude from the transmitted signal. A radar that uses the echo-phase variance to detect the target is known as a coherent radar. The noncoherent radar makes use of return amplitude fluctuations to detect a target.

2.2.2.1 Coherent Radar

The coherent radar determines the doppler component of a moving target in clutter by detecting the frequency difference between the transmitted and echo waveforms through use of the phase variance. The determination of the frequency difference requires that the receiver have a reference signal that is coherent with the transmitted waveform. Coherency also requires a knowledge of the relative velocity of the clutter with respect to the radar. Since a scanning antenna can cause a shift in the doppler frequency of the clutter, a variable filter must be used to track the clutter relative velocity, which adds complexity to the radar.

2.2.2.2 Noncoherent Radar

The noncoherent MTI radar detects targets in clutter by measuring the relative motion between the target and the clutter. Echoes from clutter will remain constant during successive radar scans, but target echoes will vary in amplitude. The rate of amplitude variance corresponds to the doppler frequency. Since a noncoherent radar does not require a reference signal, it is simpler in design than the coherent radar. The noncoherent MTI radar does require a clutter background before it can track a target, however, since the clutter itself is the reference signal.

It is possible to design the radar to switch between coherent and noncoherent operation.

2.2.3 Tracking

As mentioned previously, a radar system tracks a target by continually using an error-signal-actuated servomechanism to point the radar antenna

at the target. The difference between the target position and the radar antenna axis is referred to as the angular error. The radar system attempts to reduce the angular error to zero so that the target is located on the radar antenna axis. The speed of the angular error measurements is dependent on the type of angle tracking technique the radar uses to generate the error signal. For a tracking radar there are three methods used to generate the error signal: sequential lobing, conical scan, and monopulse.

Sequential lobing, which is rarely used in modern radars, involves switching the antenna beam between two positions to measure the error in just one coordinate. Conical scanning involves the constant rotation of an offset beam to develop the angle coordinate. Both sequential lobing and conical scanning require a number of pulses to be processed before an angular measurement can be determined.

The most modern method of tracking is monopulse. With this technique angular error information is derived on the basis of a single pulse. While this obviously speeds up the target acquisition process, it adds a great deal of complexity to the radar. As a result of this complexity, however, the monopulse radar offers better accuracy and bandwidth than either the conical-scan or sequential-lobing type radars.

3. RADAR CLUTTER AND TARGET DETECTION

Radar clutter can be broadly defined as return echoes on the radar display other than those of the desired target. Since radar return echoes are generated by everything that comes in the transmitted energy's path, clutter can be generated by trees, buildings, terrain, sea, vegetation, weather, etc. What constitutes clutter is dependent on both the radar transmitted energy and the radar operating mode. For example, in an air-to-air mode all of the ground return would be considered clutter. On the other hand, in an air-to-ground mode such as ground mapping, most or all of the ground return could be the desired radar image. Antenna and radome design, terrain reflectivity, altitude above the terrain, and other physical quantities affect the amount of unwanted radar clutter, which can mask the desired target signal.

The energy transmitted by a radar to detect and track a target is largely contained within the antenna main beam. Some small portion of this energy, however, is transmitted in spurious directions by the antenna side lobes or reflections from the radome wall. Both the main-beam and side-lobe energy transmissions contribute to radar clutter.

Clutter on a radar display makes it more difficult to detect the target. With a moving radar, the clutter can also change from scan to scan. While most clutter can be filtered out for any particular radar mode, the probability of detecting a target in clutter can decrease if the clutter is filtered. The pulse doppler radar is particularly important for airborne tracking applications because of its ability to detect moving targets even when clutter energy has a much higher echo return level than that of the target.

The desirability of an airborne tracking radar to eliminate ground clutter such as trees, houses, and slow moving targets is complicated by the desirability to add to a radar primarily optimized for air-to-air operation, air-to-ground modes to detect these same trees, houses, and slow moving targets. Additional complexity is also added to the radar when detection of both land targets and targets at sea is desired. Fortunately, all targets, whether they are on the ground, on the sea, or in the air, exhibit the doppler shift.

3.1 Types of Clutter

There are normally three types of clutter associated with airborne radars. Main-beam, side-lobe, and altitude line clutter are described in the following sections.

3.1.1 Main-Beam Clutter

Main-beam clutter results from echo returns generated by ground reflection of the main beam. The clutter associated with the main beam has a finite spread forward of the aircraft that is dependent on the antenna beamwidth. The doppler frequency shift of the main-beam clutter may be determined by using an aircraft on-board inertial navigation system (INS), permitting the clutter to be filtered before the target echoes are displayed. Since the main-beam clutter will vary with changing scanning angle and aircraft velocity, any clutter rejection filter that is used must be variable.

3.1.2 Side-Lobe Clutter

Side-lobe clutter is the result of transmitted side-lobe energy creating undesired return echoes. While the side-lobe energy transmissions are less intense than those of the main beam, they cover a larger area than the directive main beam and emanate in all directions from the aircraft.

The side-lobe clutter intensity will vary and is dependent on the aircraft speed and direction and the angle of the radar antenna beam. If the level of side-lobe energy transmitted is known, the region of side-lobe clutter can normally be calculated and the clutter rejected.

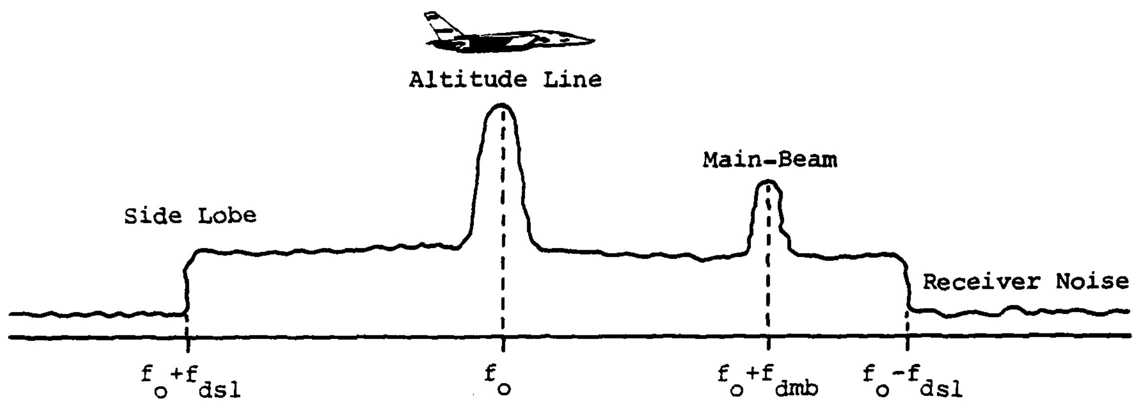
3.1.3 Altitude Line Clutter

Side-lobe energy reflecting from the ground directly beneath the aircraft creates an intense clutter level known as altitude line clutter. Altitude line clutter is not shifted in frequency because there is no vertical relative motion between the ground and an aircraft in level flight. Since there is relative motion between the aircraft and ground on either side of the perpendicular however, altitude line clutter is limited to a very narrow region directly below the aircraft. The intensity of the clutter can vary with radar depression angle and aircraft altitude.

Altitude line clutter may be rejected by gating the radar so that it rejects all signals corresponding to the altitude of the aircraft or designing a frequency rejection filter related to the transmitted frequency of the radar.

3.2 <u>Target Detection In Clutter</u>

Since radar systems use the doppler principle to detect target echoes, it is important that the radar be able to detect any frequency shifts that occur in the clutter regions. Figure A-1, which is a clutter spectrum, shows the various clutter regions associated with an airborne radar and their attendent frequency shifts.



f_o = transmitter frequency

f_{dmb} = doppler frequency shift of main beam

f_{dsl} = doppler frequency shift of side lobes

Figure A-1. AIRBORNE RADAR CLUTTER REGIONS

The doppler frequency shift (f_d) may be writtern mathematically as:

$$f_d = \frac{2V\cos\theta fo}{c}$$

where

V = is the relative velocity between the radar tracker and the target

θ = is the angle made by the intersection of the target line of travel and the radar line of sight

f_o = is the transmitter frequency

c = is the propagation velocity

The two variables, V and θ, make target detection in clutter directly dependent on target aspect at the time of detection when using a pulse doppler radar. Since the pulse doppler uses relative velocity (V) to filter incoming signals, the highest relative velocity between the aircraft and the terrain occurs directly ahead of the aircraft at the horizon ($\theta = 0$) and is equal to the aircraft ground speed. All targets whose velocity along the radar line of sight is less than that of the tracking radar's ground speed will compete with the terrain clutter contained in the return echoes.

3.3 Target Aspect

Figure A-2 shows the clutter spectrum for the radar and makes clear how critical target aspect is to detection. For head-on airborne targets, the target speed adds to the speed of the aircraft carrying the radar (maximum V, $\theta = 0$) and the resulting doppler frequency shift is higher than that of the terrain-induced clutter (V equals ground speed of the aircraft carrying the radar, $\theta = 0$). This is the so-called "clear region" for a doppler radar and accounts for good detection performance against an airborne closing target.

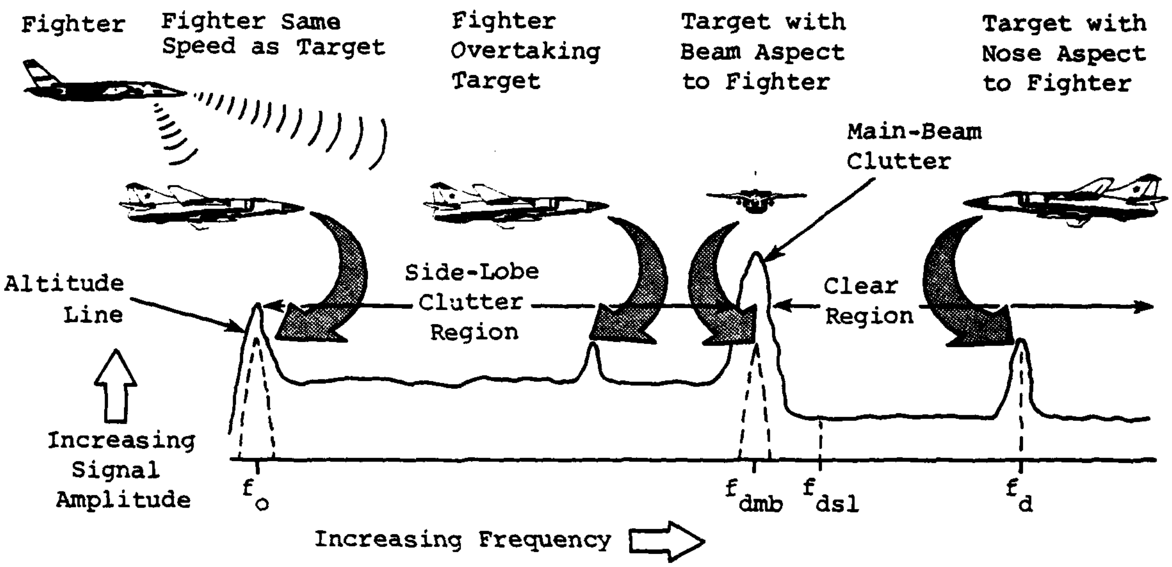


Figure A-2. TARGET ASPECTS EFFECTS ON TARGET DETECTION IN THE PRESENCE OF CLUTTER

An airborne target with a beam aspect to the tracking aircraft has the same relative velocity as the tracking aircraft ground speed and a variable angle. Therefore, it has the same doppler frequency shift as the ground return in the main beam and is obstructed by the main-beam clutter. When the tracking aircraft is closing on an airborne target from the tail aspect, the echo doppler frequency shift falls in the side-lobe clutter

region. This is because the target doppler frequency shift is proportional to the difference between the tracker and the target speeds (V is less than tracker ground speed) and is therefore always between zero doppler frequency shift (altitude line clutter: $V = 0$, $\theta = 90°$) and main-beam clutter (tracker ground speed and $\theta = 0°$). The tail aspect target must compete with relatively high levels of side-lobe clutter but not as high as in the main-beam or altitude-line. The echo return of an airborne target with the same velocity as the tracker would be contained in the altitude-line clutter region since V would equal zero.

3.4 Detection Methods

The effects of radar clutter on target detection can be reduced by designing frequency rejection filters into the radar system. The use of such narrow-band filters allows a target echo to be passed while eliminating the various frequencies making up clutter echoes. The bandwidth of each filter used is governed by the expected energy of the echo return. Banks of filters are required to cover the entire range of anticipated doppler-shifted frequencies. As may be expected, incorporating filters into the radar increases the complexity of the system.

The use of narrow-band filters by themselves has an adverse effect on range resolution because filtering affects the clarity of the return pulse shape, and high resolution requires a sharp pulse. To eliminate the loss of range resolution, frequency rejection filters can be range gated.

3.5 Filters and Range Gates

In order to establish a range-gated system, the time delays (range measurements) associated with different ranges are divided into small intervals. The system samples the echo energy at each time interval in sequence before passing the energy to a narrow-band filter. Since range resolution is established by the range gate, the filter is necessary only to detect the target echo. However, the combination of the range gate and filter also reduces the clutter in the filter.

Figure A-3 shows a series of parallel hyperbolas called isodops, which are lines of constant doppler frequency. The area bounded between a pair of isodops contains the same band of doppler-shifted frequencies with respect to the tracking aircraft. Since each hyperbolic strip covers a section of terrain, the ground clutter from the side lobes will also be present in each isodop-bounded area and will contribute to the clutter in a given radar doppler frequency filter. This is shown in Figure A-3 as the shaded area between isodops. If all of the radar returns are funneled into the same doppler filter, then a target, if it is to be detected in the filter band, must compete with the energy received from the side lobes. However, if the system is range gated, the effects of side-lobe clutter can be reduced.

Figure A-4 illustrates the effect that adding range gates can have on side-lobe clutter. Range gating a radar creates an arc with the same radius as the range to the target. When this arc is drawn across the

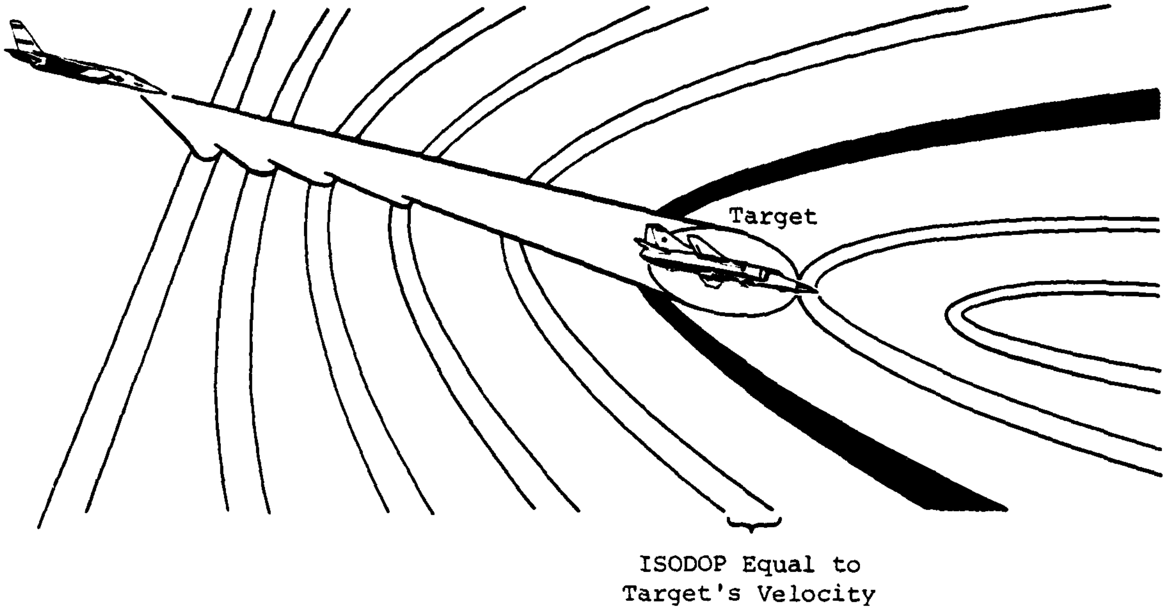


Figure A-3. AIR-TO-AIR TARGET DETECTION

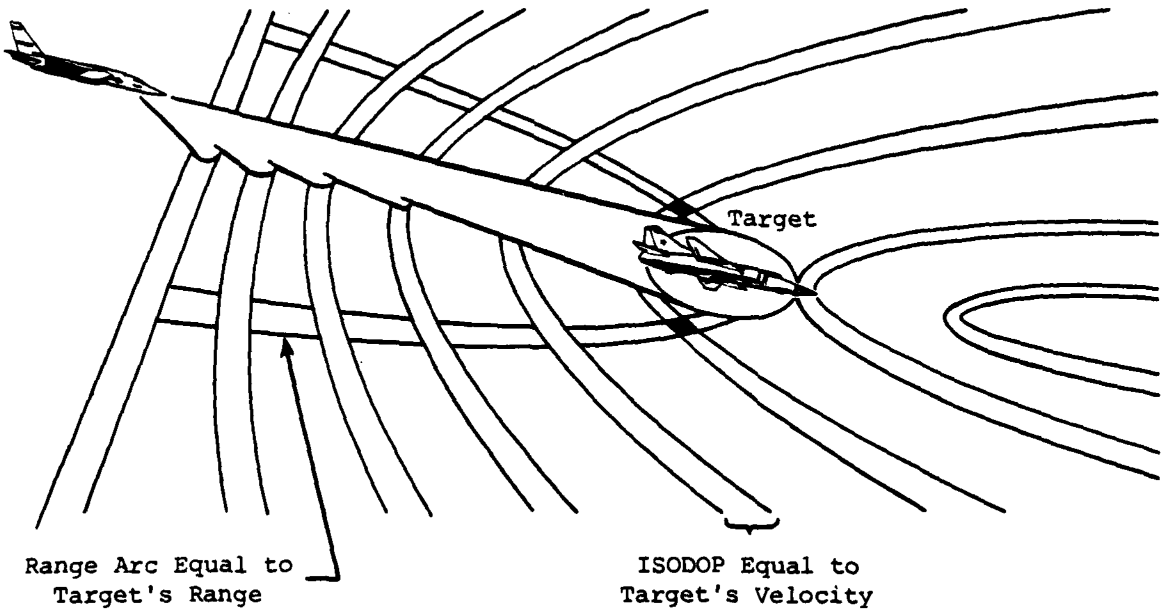


Figure A-4. AIR-TO-AIR TARGET DETECTION WITH RANGE GATING

terrain, it intersects with the various isodops. By controlling doppler frequency filter bandwidths in addition to range gating, finite range and isodop areas are defined. The intersection of the range arc with the isodop corresponding to the target doppler frequency filter defines the small section of terrain clutter with which the target must compete. The ground clutter is shown in Figure A-4 as the cross-hatched area adjacent to the target. The value of simultaneous use of range gating and different doppler frequency filters is obvious when the ground clutter of Figure A-4 is compared to that of Figure A-3.

4. RADAR OPERATING MODES

An airborne attack radar has two major modes of operation: air-to-air and air-to-ground. Each of these two modes may be further subdivided. The submodes of a radar may be manually selected through a control panel or they may automatically be activated in conjunction with the selection of another mode. As an example, automatic acquisition, which is a submode of the air combat mode, is automatically activated with the selection of the boresight, super search, vertical scan, or auto gun sub-submode in the F-15. Range while search may be a selectable mode in one aircraft and an automatically activated mode in another. Table A-1 presented a list of the operating modes desired in a modern radar system. This section defines those modes. To simplify the discussion, a distinction between submode and sub-submodes will not be made.

4.1 Air-to-Air Modes

4.1.1 Air Combat Modes

The major submodes associated with air combat are rapid search, automatic acquisition, and automatic track:

- Rapid Search. Rapid search modes reduce the area the radar scans while searching for a target. Often the area to be searched is determined by the weapon selected.
- Automatic Acquisition. In the automatic acquisition mode the radar locks on to and tracks the first target it detects. If several targets are detected, the radar will lock on to the closest target. There are normally several submodes that provide automatic acquisition:
  - Boresight Mode. The boresight mode is a "spotlight" type of acquisition in which the radar acquires and tracks targets along the aircraft boresight line. It is normally a short-range mode (10 nmi) designed for short-range missiles such as the AIM-9.
  - Super Search Mode. This mode is similar to the boresight mode in range capability but covers an area that corresponds to a heads-up display field of view (normally 20 degrees by 20 degrees in both azimuth and elevation).

•• Vertical Scan Mode. The vertical scan mode also has a limited range (approximately 10 nmi) but covers a large elevation angle (approximately 40 degrees). The azimuth angle coverage is limited (less than ±5 degrees).

•• Auto Gun Mode. For aircraft with guns, the auto gun mode will normally provide automatic acquisition of targets. The normal range covered is approximately 1/2 to 10 nmi within a 60-degree azimuth scan. Elevation is normally stabilized to the horizon with scan of approximately ±10 degrees.

- Automatic Track. When the radar is operating in the air combat mode, once it automatically acquires a target, the radar will normally go into an automatic single target track mode until the pilot designates another radar mode.

4.1.2 Normal Air-to-Air Modes

There are twelve normal air-to-air modes:

- Look-Up Mode. A look-up mode is characterized by a low PRF. It is designed to be used in a relatively clutter-free environment for targets flying above the tracking aircraft.
- Look-Down Mode. The look-down mode is characterized by a medium PRF to provide enhanced filtering of clutter from ground return. This mode is designed for targets beneath the tracking aircraft.
- Manual Acquisition. In a modern radar, all targets (up to a specific number) detected and displayed are entered in the radar memory along with the target range, azimuth, and elevation at which the detection was made. In manual acquisition, the pilot can command the radar to lock on to a specific target by bracketing the target on the radar display with some type of target designator control.
- Single Target Track. The single target track mode involves tracking one target continuously. This is normally accomplished by the pilot designating the target to be tracked.
- Track While Scan (TWS). A TWS mode allows a radar to provide sampled data from many targets (up to 10) rather than provide continuous data on a single target. The TWS mode provides data on a discrete sampled basis from scan to scan. With a rapid scan rate it is possible to construct the tracks of the various targets as their coordinates change from scan to scan.
- Long Range Search (LRS). LRS is the normal air-to-air operating mode of a modern radar. Usually this mode is designed to detect targets in the range from 10 to over 150 nmi and the PRF used depends on the range scale selected. For a range of 10 nmi, a medium PRF is normally used. For ranges for 10 to 80 nmi, interleaved medium and high PRFs are used. For ranges in excess of 80 nmi, a high PRF is used in conjunction with the range while search mode.

- Velocity Search (VS). The VS mode normally has a greater range than the LRS mode. The target returns are displayed in a velocity-versus-azimuth coordinate system. The VS mode normally increases the probability of detection at long range by using unmodulated high PRFs. This results in an ambiguous range determination and compromises target resolution.
- Range While Search (RWS). RWS can take two different forms, but in either form this mode is designed to furnish range information on any detected target. RWS used with the LRS mode in a high range setting normally involves frequency modulation of the high PRF to determine range. RWS used with the velocity search mode interleaves high and medium PRFs.
- Short Range Search (SRS). The SRS mode normally uses medium PRFs to separate target returns from short-range clutter and its maximum detection range is usually limited. This mode will normally give clutter-free presentations for short-range missile firings.
- Identification (IFF). While the IFF system is separate from the radar set, the IFF dipole antenna is normally mounted on the focal point of the fire control system radar antenna reflector. The radar PRF generator also provides a trigger to the IFF system. The radar system provides data to the IFF computer where all of the IFF data are processed.
- Non-Cooperative Target Recognition (NCTR). The NCTR mode allows long-range identification of aircraft by means of either the target's engine harmonics or metal characteristics.
- Raid Assessment (RA). The RA mode uses higher resolution techniques to determine the number of aircraft that are close together. This could be considered a form of air-to-air doppler beam sharpening.

4.1.3 Target Illumination

The target illumination mode is used for controlling semi-active homing missiles. The illuminator may be either a continuous wave or pulse type radar.

4.1.4 Helicopter Detection

The helicopter detection mode is an advanced capability presently being considered for inclusion in radar systems. Two different forms of helicopter detection are being considered. One form is similar to NCTR in that it would use the rotating blade modulation to identify the target as a low-speed helicopter. The second form being considered is a pilot-selectable ground-moving-target inhibit feature that would allow the radar to distinguish between a hovering helicopter and slow-speed ground traffic.

4.2 Air-to-Ground Modes

4.2.1 Ground Mapping

The ground mapping mode provides the radar with a map of the ground area forward of the aircraft to be used for navigation fixes, target detection, and for weapons delivery. The ground map is normally stabilized in both velocity and drift. There are various submodes in the ground mapping category:

- Ground Map Spoiled Beam (GMSB). The GMSB mode changes the shape of the beam of the transmitted energy. The spoiled beam pattern is normally opened at the bottom in order to illuminate the terrain immediately in front of the aircraft without tilting the radar reflector down to an extreme angle. This results in the radar scanning an elongated sector forward and down from the aircraft bore-sight line.
- Ground Map Real Beam (GMRB). The GMRB mode is similar to the GMSB mode except that the antenna is tilted down to illuminate the terrain with the radar's "real beam" or pencil beam to obtain an optimum display of the terrain. A pencil beam provides high gain by concentrating the radiated power in the direction of the target, thus reducing unwanted echoes from other targets and the ground.
- High Resolution. The high resolution ground mapping mode is designed to enhance the radar image in a small search area. This mode is particularly useful for navigational updates, position fixing, and target pinpointing. It has two submodes:
  - Doppler Beam Sharpening (DBS). The DBS mode is used to enhance the angular resolution of the radar ground map display. This technique uses a high-speed computer to separate closely spaced points by filtering small frequency differences in radar returns, producing a high resolution map after a large amount of data has been processed.
  - Synthetic Aperture Radar (SAR). The SAR mode processes signals to create, in effect, a long antenna. The resolution in both range and azimuth is dependent on the synthetically created horizontal aperture of the radar. Since the SAR builds a map from processed returns over a period of time, the resolution desired from the radar is tied to the data storage capacity of the system. Normally, the aperture is directed at right angles to the ground track of the aircraft, but the radar aperture can be adjusted to look ahead of the aircraft. A major problem with the SAR mode is the need to stabilize the SAR map to compensate for aircraft perturbations. While SAR is a mode in the most advanced attack radars, some aircraft carry a separate side-looking SAR.

- Freeze. The freeze mode allows the ground map to be frozen to permit fixing the position of the aircraft or examining surface features in detail. This mode normally requires a digital scan converter.

- Expand. The expand mode allows a patch of the displayed ground map to be expanded to fill the entire video display. The pilot designates both the ratio of expansion and the area to be expanded by centering the tracking cursors over the area on the radar display. In a 4-to-1 expansion mode with range settings of 80 and 40 nmi, a radar searching between 40 and 80 nmi can be expanded to show a patch 20 nmi by 20 nmi. Searching between 0 and 40 nmi, the expanded patch would be limited to 10 nmi by 10 nmi.

4.2.2 Air-To-Ground Ranging (AGR)

The AGR mode uses a low-to-medium PRF to determine the slant range from the aircraft to a designated ground point. The slant range information is used for various weapon delivery techniques, including bombing and strafing, to continuously compute both release and impact points.

4.2.3 Ground Moving Target (GMT)

The ground moving target mode allows detection of targets whose relative velocity on the ground range from some maximum down to a velocity submerged in the main-beam clutter. The GMT mode may be implemented by the use of either coherent or noncoherent techniques.

- Fast Moving Target Track. A GMT mode associated with tracking fast moving targets will track a ground target down to the main-beam-clutter energy level.

- Slow Moving Target Track. The GMT mode associated with slow moving targets permits seeing targets in the main-beam clutter.

4.2.4 Fixed Target Track (FTT)

In the FTT mode, the target is normally acquired and identified in one of the ground mapping modes. Once a fixed target is acquired, the RF energy is increased to illuminate the target area sufficiently.

4.2.5 Ship Detection and Track

The ship detection and track mode is similar to that used to track a ground moving target. The difference is the use of medium PRF to reject sea clutter combined with frequency agility and advanced filtering techniques for detecting ships in varying sea states.

4.2.6 Navigation Update

Navigation update modes are designed to determine the aircraft's true position by radar in relation to the position indicated by other on-board

sensors. These modes allow the pilot to correct any accumulated errors in the aircraft's navigation system.

- Position Update. The aircraft's position can be updated automatically by accurate fix-taking in the beacon mode or by measuring the changing angular orientation to a navigation reference point by determining the magnitude of the doppler shift from a high resolution mode.
- Velocity Update. In the velocity update mode, several doppler-shifted echo returns at different angles from the ground are used to determine a velocity update for the aircraft's inertial navigation system.

4.2.7 Terrain Avoidance (TA)

When operating in the TA mode, the radar sweeps on either side of the designated ground track and displays all of the terrain at or above a preselected clearance plane and on either side of the ground track. The plane is chosen to provide the desired clearance between the aircraft and the terrain.

4.2.8 Terrain Following (TF)

In the TF mode, a monopulse beam is used to derive command signals that will cause the aircraft to fly along the contour created by the intersection of obstacles and the clearance plane. The TF mode normally requires the use of a radar altimeter to generate descent commands. The actual TF generated commands depend on the aircraft dynamics as well as the radar information rate.

4.3 Special Modes

Besides air-to-air and air-to-ground modes, radars also incorporate special modes to enhance the aircraft's capabilities in both a friendly and hostile environment. Some of these are discussed below.

4.3.1 Beacon Mode

The beacon mode provides a low-PRF radar-beacon-interrogation transmission and displays beacon reply codes. The air-to-air beacon mode may be used for maintaining aircraft separation, joining a formation, and refueling in flight. The air-to-ground beacon mode presents the relative angles between the ground beacon and the transmitting aircraft, enabling direct interpretation of relative bearing for tracking, homing, or other navigation purposes using a ground beacon reference.

4.3.2 ECCM Modes

Radar ECCM modes are designed to determine the presence and location of active ECM devices, to automatically adapt the radar for search and acquisition performance against both noise and repeater type jammers, and

to optimally configure the radar to maintain tracking performance against the threat. The radar automatically changes the mode of operation to that configuration best suited to counter the specific threat detected, allowing for automatic or manual channel select to enable the pilot to look for a clear channel within the RF band. Some nominal number of channels could be selected. The F-15, for example uses six.

If jamming is detected during track, the radar will lock on the target in angle and then extrapolate target range and range rate by using the last measured target radial speed and current line-of-sight speed.

4.3.3 Television (TV) Mode

The TV mode of operation is designed to be used with electro-optical (EO) weapons. When using an EO guided bomb, a TV image is presented on an aircraft multidisplay screen from the camera in the weapon. The radar system, regardless of the information displayed, will continue to operate in the mode selected.

4.3.4 SNIFF Mode

SNIFF is a passive radar mode that has a manual active search capability with minimum transmitter time. When using the SNIFF mode, the radar operates receive-only to detect noise jamming, is manually activated for transmission, then shifts automatically to radar silent surveillance until the active mode is again initiated.

APPENDIX B

WARRANTY SUPPORT PLANS AND CONTROLS

1. INTRODUCTION

Long-term warranties and guarantees are finding increased use in the procurement of military avionics systems as a possible means of improving operational reliability and maintainability and, in turn, reducing life-cycle cost. This appendix reviews the several forms that warranty may take, including the reliability improvement warranty (RIW), the MTBF guarantee, and logistics support cost (LSC) guarantee.

As an aid to this discussion, the following definitions are provided:

- Warranty - a contractual obligation that provides incentives for the contractor to satisfy user system field operational objectives
- Reliability Improvement Warranty (RIW) - a fixed price commitment that involves contractor repair or replacement of defective equipment discovered during the period of coverage
- Guarantee - a commitment embodying contractual incentives, both positive and negative, for the achievement of specified field operational goals

2. WARRANTY PLANS

Three basic types of warranty plans have been employed:

- Reliability Improvement Warranty (RIW)
- MTBF Guarantee
- LSC Commitment

Table B-1 highlights some of the principal features of these three types of plans. Chapter Six provides their definitions.

Although several recent applications of RIW have included the MTBF guarantee, the RIW plan is a useful concept when applied by itself. The logistics support cost commitment has been used as an alternative to the RIW control method.

Table B-1. FEATURES OF ALTERNATIVE WARRANTY PLANS			
Features	RIW	RIW/MTBF	LSC
Objective	Secure reliability improvement/reduce support costs	Achieve stated reliability requirements/reduce support costs	Achieve stated logistic-cost goal
Method	Contractor repairs or replaces all applicable items that fail during coverage period; implements no-cost ECPs to improve reliability	Same as RIW, plus contractor provides additional spare units to maintain logistic pipeline	Normal military maintenance; operational test performed to assess LSC; penalty or corrective action required if goals are not achieved
Pricing	Fixed price	Fixed price	Fixed price or limited cost sharing for correction of deficiencies
Incentive	Contractor profits if costs are lower than expected because of improved R&M	Similar to RIW, plus possible severe penalty for low MTBF	Award fee if goal is bettered; penalties for poor cost performance

2.1 Reliability Improvement Warranty

If RIW is applied, it is necessary to establish an agreement setting forth the terms and conditions for the warranty. A typical agreement should include:

- Statement of Contractor Warranty. This will contain the basic agreement, requirements for corrective action, exclusions and limitations, extent of warranty coverage, requirements for maintenance facilities, and cost-related information.
- Contractor Obligation. Collateral contractor obligations regarding ECPs, warranty marking and seals, turnaround time and penalties, and data requirements are noted.
- Government Obligations. Requirements for Government warranty administration, timely approval of ECPs, and provision of data are detailed.

The decision to include an RIW clause in a procurement contract should not be made lightly. The proper approach involves a great deal of effort

in formulating effective procurement, administrative, and logistic provisions. Table B-2 highlights some of the advantages and disadvantages of using RIW.

2.2 MTBF Guarantee

Because of possible problems in determining the relevancy of failures, the MTBF plan is considered feasible only where the contractor either performs the maintenance (RIW or contract maintenance) or has the facility to monitor the maintenance process. Such restriction is also necessary for assuring effective corrective action. The notation *RIW/MTBF* is used for such combined form of warranty.

The MTBF provisions cover the following topics:

- Basic Guarantee. A schedule of MTBFs required to be met by the equipment in the field for specified periods is established.
- MTBF Definition. Countable failures are defined, and the time base for computing MTBF is stated.
- Compliance Determination. Frequency of MTBF measurement is specified along with a formula for computing consignment-spares requirements in the event the unit does not meet MTBF requirements.
- Contractor Corrective Action Requirements. The additional action to be taken by the contractor to achieve the required MTBF levels is stated.
- Consignment-Spares Administration. Provisions are outlined for spares obligation, delivery, Government return, and ownership conversion.
- Data Requirements. Data to be developed by the contractor in support of the MTBF guarantee are specified.

In recognition of the added risk the contractor takes in offering this guarantee, the contractor will include his price for this protection in his bid, perhaps as a separate line item, if directed to by the Government. The procuring agency must then determine if the protection provided is cost-effective in relation to the contractor's price.

2.3 LSC Commitment

There is considerable variation among LSC commitment plans regarding the action taken as the result of the operational test. Most plans, in the event of achieving a lower measured LSC, provide the award fee predicated on the amount by which the goal is underrun. In the event of an overrun, the plans provide for reducing or eliminating the award fee. In addition, some recent plans have required the contractor to take corrective action to achieve the stated goals or be penalized monetarily. In recognition of the risk inherent in this concept, the contractor bids a fixed price for undertaking a commitment where corrective action may be required. These types of plans are considered to fall under or are an adjunct to correction-

Table B-2. SUMMARY OF RIW ADVANTAGES AND DISADVANTAGES		
Factor	**Advantages**	**Disadvantages**
Procurement Considerations	Initial requirements for AGE, data, training, module spares, R&M program elements, etc., are reduced, thus reducing the complexity of the procurement. Significant portion of support costs is known at the outset.	Close coordination with user, logistic, and legal activities is necessary until RIW contracting experience is acquired in developing appropriate terms and conditions, including any necessary escalation provisions. Contract price adjustments may be required periodically, and potential for legal disputes on liability is increased.
Reliability/ Maintainability	Contractor and government have same goal of achieving good R&M characteristics. Growth can be achieved in faster and more cost-effective manner than with organic maintenance because of contractor incentives. Limited military maintenance will reduce maintenance-induced failure occurrences. More realistic contractor claims on operational reliability than for usual procurements.	Care has to be exercised to ensure that design for R&M and R&M ECP changes will be compatible with organic maintenance after transition from RIW.
Hardware Acquisition Costs	Will be reduced if formal R&M program requirements are relaxed.	Will be increased if the contractor expends additional effort in achieving good initial R&M, or because of risk protection.
Spares Cost	Will be decreased because better reliability is achieved and control of depot-type repair turnaround time is exercised.	Could lead to increased costs because of sparing at the LRU rather than module level and because of possibly long pipeline time to and from the contractor.
Maintenance Personnel Requirements	Reduced requirements for skilled base and depot maintenance personnel.	At transition to organic maintenance, a large increase in the number of skilled maintenance personnel may be required.
AGE	Limited requirements for initial base and depot AGE. Purchase of such AGE at transition will be for a stabilized design. AGE support cost under RIW is also reduced.	In the event early and fast introduction of military maintenance is required, necessary test equipment may not be available.
Training and Data	Initial requirements and costs are reduced. At transition, design will be stabilized, leading to better requirements definition.	Planning for a single, step-function organic maintenance takeover required. Training of cadre of military personnel during the RIW is recommended.
Logistic Management and Administration	Maintenance at the "box" level reduces management costs. Better R&M data will be available through warranty data records.	New or modified procedures need to be developed to support the warranty concept without adversely affecting the logistic management function. Ability to respond to an emergency situation may be impaired. Fast ECP evaluation necessary for most effective R&M growth.
Contractor Aspects	Long-term, stabilized work flow and parts demand. Good profit for good equipment. Increased chances for follow-on awards if RIW services are satisfactory and because of greater knowledge about equipment performance in operating environment.	Pricing risks are high. RIW implementation involves a greater-than-usual degree of good faith on both sides. Some problems may arise because of rigid government regulations or changes in government personnel.

of-deficiencies (COD) clauses. In the event the cost of correction of deficiencies exceeds the contractor's bid amount, provision may be made for cost sharing between Government and the contractor of the overrun up to some specified ceiling. Costs beyond the ceiling must be borne solely by the contractor.

3. WARRANTY CONTROL TECHNIQUES

As an aid in selecting among the alternatives believed most compatible for Air Force CMMR procurement at this time, Table B-3 presents a comparative analysis of the effectiveness of the RIW, RIW/MTBF, and LSC commitment plans with a standard procurement using organic maintenance included as a point of reference.

Table B-3. **COMPARISON OF PROCUREMENT METHODS**

Factors	Standard Procurement and Maintenance	RIW	RIW/MTBF	LSC/Organic Maintenance
User Risk in Achieving Objectives	High	Moderate	Low	Moderate to high
Contractor Pricing Risk	Low	Moderate	High	Moderate
Administration Difficulty	Low	Moderate	High	Low to moderate
Enforceability Risk	N/A	Moderate	Moderate	Moderate to high
Contractor Reliability-Improvement Motivation	Low	Moderate	High	Low to moderate
Commitment Time	N/A	Start of Production	Start of Production	After follow-on operational test
Services Provided	N/A	Depot maintenance plus no-cost ECPs	Depot maintenance, logistics assets if required, plus no-cost ECPs	Logistics assets if required or equipment ECPs
Logistic Management Difficulty	Low	Moderate	Moderate	Low

Since warranty is considered to provide a high degree of contractor motivation and responsibility for product quality and performance, the relationship between the use of warranty and some of the traditional control techniques are reviewed next.

3.1 Reliability Program Interface

How a warranty program such as an RIW relates to usual military reliability-program requirements is still an open question. Buying equipment under an RIW is a step toward emulating the overall procurement approach successfully used in many commercial areas. In these areas, however, formal reliability program requirements are rarely imposed on the producer, at least not in the usual military manner in which specific standards and specifications are included in the contract.

Until further experience is gained on how an RIW or other warranty plan affects the reliability program activities of development contractors, it is recommended that reliability program elements be relaxed most cautiously during development, and only on carefully selected programs.

For the production contract, the direction is somewhat clearer. At that point, the warranty commitment will have been made and a continuing requirement for such efforts as costly periodic reliability acceptance sampling tests may not be cost-effective. Again, until experience is gained, caution should be exercised. One approach used in a recent Air Force avionics RIW/MTBF procurement was to include applicable reliability and maintainability test requirements for production units in the contract but only for the initial delivery. This provides assurance to the Government that the production units can meet R&M performance goals and the RIW warranty program will assure that follow-on production units will also meet the goals.

3.2 Maintainability

Field maintainability, such as on-equipment or base-level MTTR, is not directly controlled by current warranty (RIW) plans. Although the warranty may contain requirements for contractor turnaround time, these requirements include, in addition to repair time, actions to provide for receiving inspection, repair scheduling, and preparation for reshipment. There is evidence that contractors may improve the maintainability characteristics of their equipment to reduce warranty manpower expenditures. However, if there is a mission requirement to achieve some specified field MTTR, the use of MIL-STD-470, *Maintainability Program Requirements*, and MIL-STD-471, *Maintainability Demonstration*, is considered necessary during development regardless of warranty utilization for production equipment. Also, in most cases the Government will eventually assume maintenance responsibility; therefore, normal controls should be exercised. An alternative is the application of a guarantee plan that specifies one or more maintainability-control parameters.

3.3 Configuration Control

Most applications of warranty by the military have made use of standard configuration-control practices as defined in MIL-STD-480, *Configuration Control - Engineering Changes Deviations and Waiver*, and MIL-STD-483, *Configuration Management Practices for System Equipment, Munitions, and Computer Programs*. The purpose of such use is to assure that the equipment's configuration status is known and is compatible with the intended maintenance concept upon maintenance conversion and that intersystem interface is controlled. However, expeditious processing of ECPs, especially during the production phase, is most important.

3.4 Design-to-Cost (DTC)

The design-to-cost concept, which originated with DoD Directive 5000.1 and is further defined in DoD Directive 5000.28, requires that design-to-cost

parameters be established for major weapon system procurements. As currently applied, the cost parameters represent unit acquisition (production) cost, although DoD spokesmen quickly point out that such goals should be set only with full cognizance of the life-cycle-cost implications. The use of warranty is considered to have moderate impact on design-to-cost, with the interaction stemming from added costs of production that the manufacturer might incur as a result of increased parts testing, reliability evaluation, burn-in, etc. Resulting reliability improvement should reduce support costs to more than offset acquisition-cost increases. In summary, DTC is considered fully compatible with a warranty program, including RIW, RIW/MTBF plans, or LSC commitment plans.

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